GROUND WATER RESOURCE DEVELOPMENT AND AUGMENTATION IN PARTS OF NATIONAL CAPITAL TERRITORY, DELHI

DISSERTATION

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF

Master of Philosophy

IN

GEOLOGY

(Hydrogeology)

By

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Under the Supervision of

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2004-2005

Dedicated

to my

Parents

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CERTIFICATE

This is to certify that the work presented in this dissertation entitled, **"Ground Water Resource Development and Augmentation in parts of National Capital Territory, Delhi"** has been carried out and completed under my supervision in the field of Hydrogeology at the Department of Geology, Aligarh Muslim University, Aligarh.

This work is an original contribution to existing knowledge of the subject. I recommend that **Mr. Azeem Akhter** be allowed to submit the dissertation for the award of the degree of **Master of Philosophy** in **Geology** of the Aligarh Muslim University, Aligarh.

Khurshid

(Dr. Shadab Khurshid)
Reader

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ACKNOWLEDGEMENTS

I have first to bow my head in front of the Almighty God for his constant shower of blessings, which made this task accomplish bearing all phases of ups and downs.

I feel privileged in expressing profound sense of gratitude and indebtedness to my supervisor, ***Dr. Shadab Khurshid****, Reader, Department of Geology, Aligarh Muslim University, Aligarh for his scrupulous and keen witted guidance, encouragement and constant supervision during the entire course of this investigation.*

I take an opportunity to offer my sincere thanks to Prof. S.H. Israili, Chairman, Department of Geology, A.M.U., Aligarh for extending necessary facilities whenever I needed during my research work.

I consider it my humble and earnest duty to place on record my gratitude to Dr. S.B. Singh (Office Incharge, CGWB), Mr. Moinuddin (Scientist, CGWB) and Mr. S.K. Singh (CGWB).

I am highly thankful to Dr. Shakeel Ahmad (S.T.A.) for his kind cooperation and invaluable assistance in the analytical work performed in chemical lab. of Geology Department. Appreciations are also due to Dr. Zaheeruddin, Pradeep Kulshrestha, Ashish Dutt and Naushad Khan. I have also relied upon many colleagues and friends for ideas and critical appraisal.

I must acknowledge my indebtedness to the officers of Central Groundwater Board of Delhi for providing me a relevant literature and giving productive suggestions. Helps received from other government organizations are thankfully acknowledged.

Heartiest thanks are also due to my friends Ziaur Rehman Ansari, Mohammad Ahmad, Mairaj Ahmad and Aaftabuddin who in their capacity always encourage me during the course of study.

Last but not the least, I tender my deep sense of gratitude to my beloved parents, brothers, sister and my wife for their constant inspiration, encouragement and moral support in completing the research work.

I am also thankful to Mr. Kafeel A. Khan who painstakingly typed my manuscript.

Azeem Akhter

(Azeem Akhter)

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Introduction

INTRODUCTION

Water is a universal solvent and is a major constituent of all living organisms. Availability and absence of water influence the distribution and abundance of plants, animals as well as human societies. Earth is the only planet where water exists in all its three phases.

The water precipitates in the form of rain is the primary source of fresh water on our planet. Glacier, rivers, lakes, springs and wells are secondary sources and all of them are fed by rain or snow.

Most of rainfall in India takes place under the influence of southwest monsoon between June to September except Tamil Nadu. The rainfall in India shows great variation unequal seasonal distribution, still unequal geographical distribution and the frequent departures from the normal.

Groundwater is defined as "subsurface water in the zone of saturation including water below the water table and water occupying cavities, pores and openings in underlying rocks.

It slowly flows through the underground porous substratum from one place to another under the influence of gravity.

The total exploitation potential of groundwater amounts to 42.3×10^{10} cubic metres in India. A quarter of it is already being used in the country for irrigation, industries as well as domestic purposes. In many places groundwater withdrawals have already exceeded the recharge rates causing serious problems.

The total amount of freshwater is more than enough to meet the present and future needs of mankind. The groundwater situation in an urbanized area like Delhi is inextricably linked with growth in population, population density, water availability from different sources, water use and demand for different purposes, hydrogeology, rainfall and landuse pattern changes, provisional basic services and the degree of economic development.

The water requirement of National Capital Territory of Delhi (NCT, Delhi) is mainly to fulfill the drinking water needs of its growing population. The NCT of Delhi occupying on area of 1485 sq. km. as six administrative blocks namely:

1. City (470 sq. km.)
2. Alipur (259 sq. km.)
3. Khanjhawala (275 sq. km.)
4. Najafgarh (253 sq. km.)
5. Mehrauli (149 sq. km.)
6. Shahadara (79 sq. km.)

Delhi encompasses three local bodies viz. Municipal Corporation of Delhi (MCD), New Delhi Municipal Committee (NDMC) and Delhi Cantonment Board (DCB). Out of the capitals total area of 1485 sq. km. MCD occupies an area of 1397.29 sq. km. (94.22%), where NDMC and Cantonment area of 42.74 sq. km. (2.88%) and 42.97% sq. km. (2.90%) respectively.

Out of the total 1485 sq. km. the urban area including the new settlement in rural habitations account for about 496 sq. km. as per 1991 causes the population of Delhi which is now to be round 200 lacs. Beside, a floating population of 3 to 4 lacs is a common features of the territory. According to recent survey more than 50% of Delhi population lives in about 1304 unauthorised colonies, 44 resettlement colonies and 209 rural villages based on the present water availability.

Delhi has less than 15% of its own water resources to meet the needs. The bulk of the water supplies come from neighbouring state. The rapid growth of population exerts increasing stress on the water supply infrastructure of the NCT, Delhi.

1.1 Sources of water supply:

The river Yamuna is the only perennial river flowing in the territory. Eastern and western Yamuna canals taking off from Tajewala and the Agra canal taking off from Okhla, are the three major canal system, originating from the river Yamuna. The water resources in territory can be broadly categorized as follows:

(1) Rainwater

(2) Surface water allocations from Himalayan rivers (including Yamuna water)

(3) Groundwater resources

The water being utilized from these sources is not enough to fulfill the total demands of drinking water, creating water shortage and there is need and scope to conserve and to augment the present water availability. Implementation of artificial recharge techniques in NCT, Delhi carried out on a large scale to augment the groundwater reservoir.

Artificial recharge to groundwater is process by which the groundwater reservoir is augmented at a rate exceeding that obtaining under natural conditions of replenishment. Through rainwater harvesting augment and developed the groundwater reservoir. Various techniques of artificial recharge have been used to augment the groundwater in NCT, Delhi.

Groundwater recharge from rainwater harvesting is widely used in NCT, Delhi. Rooftop harvesting system is widely used to augment the groundwater reservoir in NCT, Delhi.

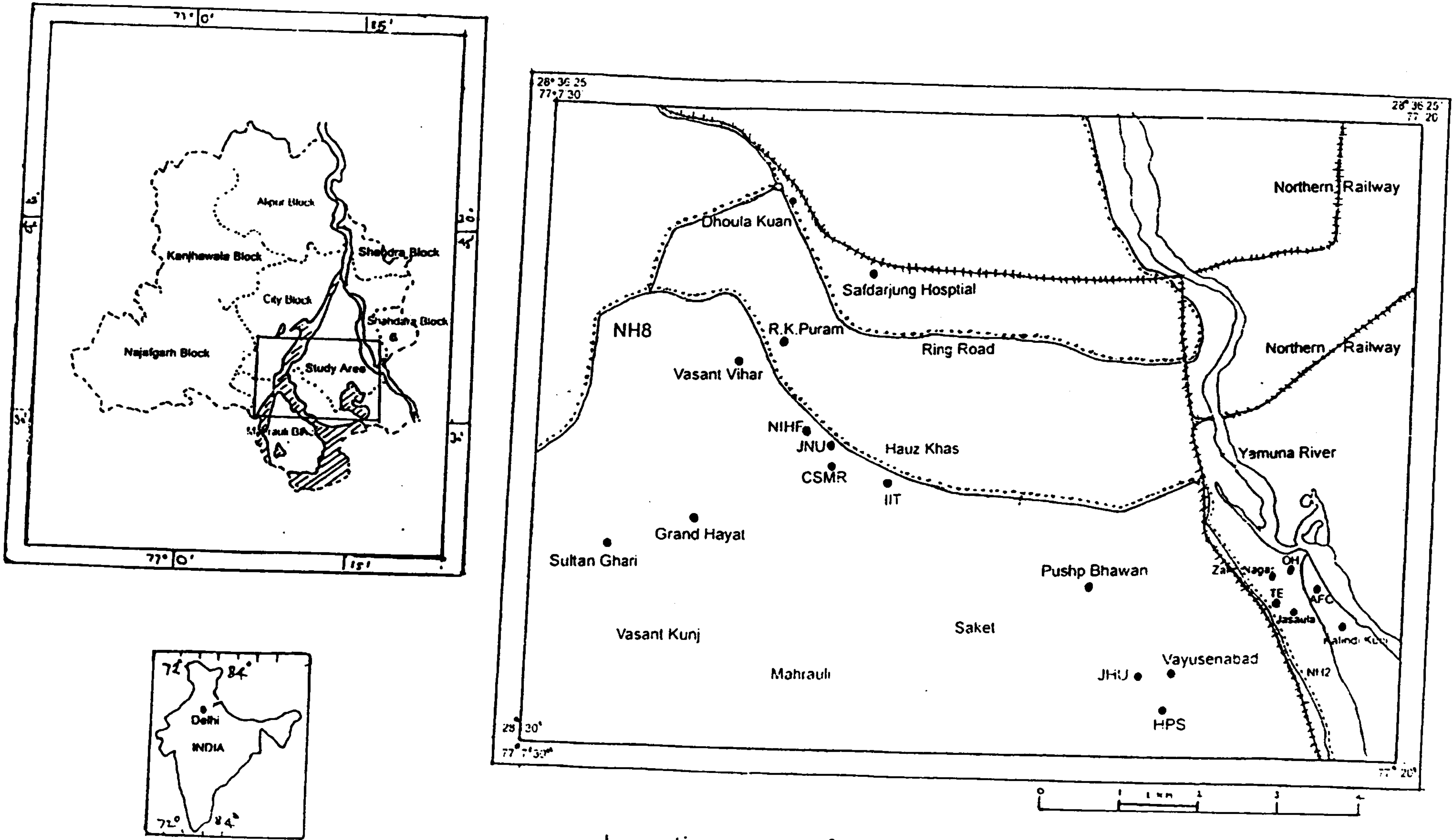
1.2 Location and Area:

The NCT, Delhi with an area of 1483 sq. km. is situated between the Himalayas and Aravallis range in the heart of the Indian sub-continent. The major part of the territory lies on the western side of Yamuna, only some villages and urban area of Shahadara lie on the eastern side of the river. Its greatest lenth is around 33 miles and the greatest breadth is 30 miles. Delhi's altitude ranges between 213 m and 305 m above sea level. The NCT, Delhi shines with the refluted glory of metropolis that functions of the capital of India.

The study area (South Delhi) located within the latitude 77°7′30" west - 77°20′ east and longitude to 28°30′ south – 28°36′25" north. It is surrounded by Noida district of Uttar Pradesh on the eastern side across the river Yamuna, on western side by Gurgaon district of Haryana. Northern part surrounded by North Delhi. NCT, Delhi population at present is 137.83 lacs (census of India 2001).

Rapid increase in population of South Delhi there are a lot of environmental problems. Due to urbanization towards South of NCT, Delhi, there is a depletion in groundwater level day by day. Growing population is the main reason of groundwater depletion in South Delhi. Groundwater is the main source of drinking water supply. Industries have

Figure-1.



Location map of the study area.

their own tubewells and there are large number of hand pumps, dry wells and shallow tubewells in the rural areas as well as in urban areas.

The area experiences severe heat during summer in the month of May and June. The highest temperature is recorded around 45°C in these months. The winter from December to February. The sever cold during December to last January when the minimum temperature is less than 5°C. The rainfall occurs between the month of July to September. The normal annual rainfall in the NCT, Delhi is 611.8 mm. The hourly intensity of rainifall in Delhi is 43.7 mm/hr in two years return period and about 20 to 25 mm in one year return period. Recharge structures are designed for hourly intensity of rainfall in one years return period.

Surveys conducted by the Central Groundwater Authority (CGWA) in the year 2004 suggested the groundwater level has gone down by as much as 10 meters over the past year in some South Delhi areas. The lowest level of water was noticed in Lado Sarai.

The average rate of depletion in Delhi in entire Delhi is 3-4 meters per year.

1.3 Previous Work:

The earliest geological mapping in the area dates back to 1917 by Heron, who grouped the hard rocks of Delhi into Alwar series of Delhi system.

Taylor (1935) carried out statistical analysis of rainfall and water level data in parts of Ganga basin. After comprehensive study and field experiments on transmitting capacity of water bearing formations, he suggested that in alluvial tract the tubewell of 1.5 cusecs capacity spaced to a mile to one and half mile apart can safely be operated without only appreciable depletion in regional water table.

Auden (1936) has carried out hydrogeological investigation in Gangetic alluvial tract of Uttar Pradesh.

Geddes (1960), Sharma and Sharma (1973), Pal and Bhattacharya (1979), Srivastava (1983), Khan et al. (1988) and Ghosh and Singh (1988) discussed different aspect of geomorphology in Gangetic plain while Rao (1973) made systematic study on the sub-surface geology of the Indo-Gangetic plains.

Khurshid (1988) assessed the pollution of river Yamuna, which is the lifeline for domestic water supply for Delhi. The stretch of Yamuna along Delhi Metropolis is about 48 km, it is heavily polluted by domestic and industrial wastewater. The water of upstream of Wazirabad is fit for drinking after treatment.

In 1947 the water table in Delhi was 30-40 feet bgl it sustained shallow wells and Baolis, at present it has gone down to 300 to 350 bgl in some areas of NCT, Delhi (II'2000). Central Groundwater Board

(CGWB, 1996) suggests that due to immense population, pressure on the city of Delhi and enormous industrialization the need of water has increased in manifolds. It can be appreciated from the fact that in 1991 the requirement of domestic water in Delhi was 64.3 million cum annually, whereas in 2001 it was projected at 98.1 million cum annually.

Surveys conducted by the Central Groundwater Authority (CGWA) in the year 2004 suggested the groundwater level has gone down by as much as 10 meters over the past year in some South Delhi areas.

1.4 Methodology:

The following methodology has been adopted for M.Phil. Dissertation:

(1) Consultation of available literature on the subject.

(2) Field survey of the research area and preparation of geological, hydrogeological map of the area.

(3) Estimation of drinking water requirement and availability.

(4) Detailed study of physiography, geology and hydrogeology of the research area.

(5) Hydrogeological mapping of the area and delineation of various aquifers.

(6) Monitoring of water table in pre- and post-monsoon period.

(7) Aquifer system and its characteristics.

(8) Regional survey and groundwater quality assessment.

(9) Groundwater development scenario.

(10) Groundwater recharges techniques.

(11) Groundwater recharge from rainwater harvesting.

(12) Environmental impact on groundwater.

Chapter 2

Geology of the area

GEOLOGY OF THE AREA

Physically, the NCT, Delhi can be divided into three segments or parts – the Yamuna flood plain, the ridge and the plain. The Yamuna flood plains are somewhat low-lying and sandy and are subject to recurrent floods. This area is also called Khadar. The ridge constitutes the most dominating physiographic feature of this territory. It originates from the Aravalli Hills of Rajasthan and entering the NCT, Delhi from South extends in a north eastern direction. It encircles the city on the northwest and west. The point near Bhatti has a height of 1045 feet. Tughlaqabad Fort is located on one of the highest spurs of the ridge.

The whole space between the river Yamuna and the ridge which has a triangular shape with an apex at Wazirabad and the base extending between Tughlaqabad and Mehrauli hasd been the site of various cities and bears the name of Khandrat (ruins). Leaving aside the Yamuna flood plain (Khadar) and the ridge, the entire area of the NCT, Delhi is categorized as Bangar or the plain. A major proportion of the area of Delhi is plain and on this area located Delhi, New Delhi and Delhi Cantonment alongwith a vast stretch of numerous villages. The land of the plain is mostly fertile.

The Delhi region is a part of Indo-Gangetic Alluvial plains, at an elevation ranging from 198-220 m above MSL, transacted by quartzite ridge extending roughly from northeast to southeastern part of the area.

A ridge forms the principle watershed of the area and acts as groundwater divide between the western and eastern part of the Delhi area. The thickness of alluvium in eastern and western side of the ridge is variable. Ridge is generally thicker (>300m) towards west, covering parts of southwest districts.

2.1 Physiography:

India divided into three strikingly well marked regions. The first is peninsular shield lying to the south of the plains of the Indus and Ganga river system. The second division comprises the Indo-Gangetic plains stretching across northern India from Assam and Bengal on the east, through Bihar and Uttar Pradesh, to Punjab and Sindh on the west. The third is extra peninsular mountains region forming Himalayan ranges.

The Indo-Gangetic plain in which the study area lies, is a deep crustal trough filled with quaternary sediments through the streams of Indus, Ganga and Brahmaputra river system. The Gangetic plain occupying the central position in the Indo-Gangetic plain is a foreland basin which is subjected to compressional forces due to underthrusting of Indian plate.

The area is occupied by quaternary alluvium and Precambrian Alwar quartzite of Delhi system. The Delhi system lies over the gneisses and the Railos with a great unconformity and is in turn overlain unconformably by the Vindhyans. The Indo-Gangetic plain is divided into four shelf areas separated from one another by three transverse highs, the Delhi Muzaffar Nagar Ridge, Faizabad Ridge and Monghyr-Saharsa Ridge from West to East (Fig. 2). Near the western margin of Gangetic plain the rocks of Delhi-Aravalli tectonic trend continue towards north to northeast. The thickness of alluvium over this Delhi ridge is much reduced on the middle part of Gangetic plain, a basement ridge structure, commonly known as Faizabad ridge exists as a continuation of Bundelkhand massif. This ridge also shows reduced thickness of the alluvium. Monghyr-Saharsa ridge is a continuation of Satpura trend which extends below the alluvium in the eastern part of Gangetic plain.

The surface stands out as linear ridges flattish at the top and rises about 70-120 m above the surrounding highest alluvial surface (GSI, 1980). Data about depth to bed rock from boreholes reveals the continuity of the Alwar quartzites beneath the quaternary alluvium in a north easterly to north westerly direction but at depth, the basement has an over all easterly slope and is faulted and fractured.

The strike of the rock outcrops (Alwar quartzite) varies from N-S to NE-SW with dip towards east and southeast in the north and west to northwest in the south. The stratigraphic sequence of the area is as follows:

Geological Succession

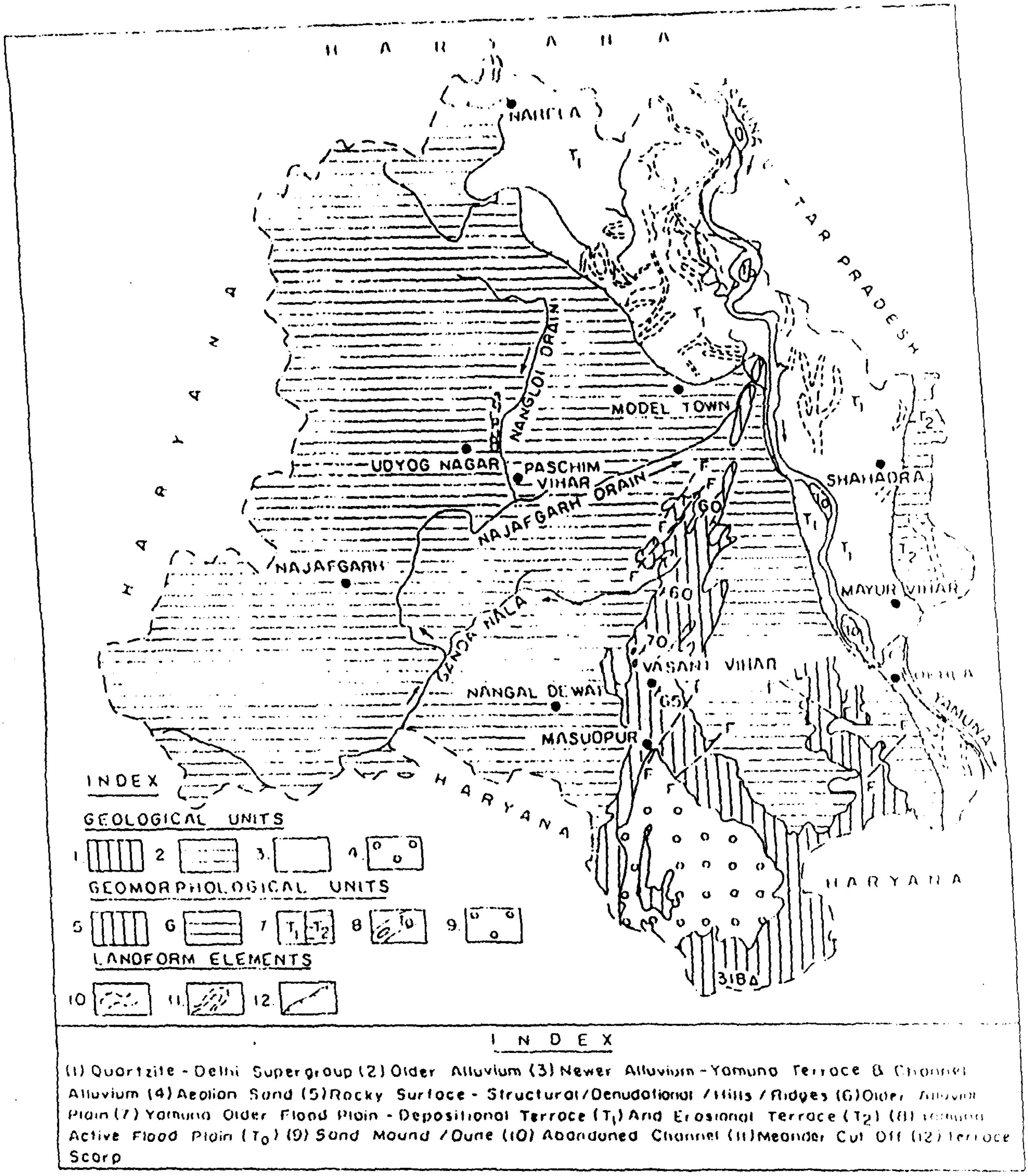
Quaternary	Newer Alluvium	Unconsolidated, inter-bedded lenses of sand, silt gravel and clay in narrow flood plains of Yamuna river.
	Older Alluvium	Unconsolidated inter-bedded inter-fingering deposit sand, clay and kankar. Moderately sorted. Thickness variable, at places more than 300 metres.
Pre-Cambrian	Alwar Quartzites	Well-stratified, thick-bedded brown to buff colour, hard and compact intruded locally by pegmatite and quartz veins inter-bedded with mica schists.

Alluvial Deposits

The alluvial deposits of Quaternary age are mainly composed of unconsolidated clay, silt, sand with varying proportion of gravel and kankar. The alluvial formation is further divided into.

(1) Newer alluvium belonging to recent age and refers to the sediments deposited in the flood plains of Yamuna river and also along water

Figure-2.



GEOLOGICAL AND GEOMORPHOLOGICAL MAP OF DELHI AREA coarses of major streams flowing form the hills. These sediments range in texture form clay/silt mixed with tiny mica flakes to medium/coarse sand and gravel. Newer alluvium in general is characterized by absence of permanent vegetation (due to periodic flooding) and lack of kankar.

(2) Older alluvium are the sediments deposited as a result of past cycles of sedimentation of Pleistocene age and occurs extensively in the alluvial plains of the territory. This comprised of inter bedded, lenticular and inter fingering deposits of clay, silt and sand ranging in size from very coarse with occasional gravels. The kankar or secondary carbonates of lime occurs with clay/silt and sometimes as hard/compact. Older alluvium is predominantly clayey nature in major parts of territory excepting the nearly closed alluvial basin of Chattarpur where the alluvial formation is derived from the weathered quartzites rocks.

Hard Rock Formation (Alwar Quartzite):

The Alwar quartzites of Delhi System exposed in the area belong to Pre-Cambrian age. The quartzites are pinkish to grey in colour, hard, compact, highly joined/fractured and weathered. These occur with interbeds of mica-schists and are intruded locally by pegmatites and quartz veins. The strike of these rocks varies NE-SW to NNE-SSW with steep dips towards SE and east except for some locally variations due to folding. The prominent joint sets are strike joints, bedding joints and dip joints. Quartzites are ferruginous and gritty types on weathering and subsequent disintegration give rise to coarse sand (Badarpur sands). Chemical weathering of deeper horizons is also common.

Sub-Surface Configuration:

The exploratory drilling undertaken has brought out the surface configuration of rock formation and depth to bedrock in different parts of NCT of Delhi. The nature of bedrock topography is rendered uneven due to existence of sub surface ridges. Thickness of alluvium overlying the quartzites increases away from the outcrops. The thickness of alluvium is 300 m or more n most parts of Najafgarh, Kanjhawala and Alipur blocks while in the SE parts of Alipur block, it varies from 100 to 300 m in the eastern parts of Najafgarh Block, the thickness range is from 50 to 300 m. In the city block, west of the ridge, the alluvium thickness increases away from the ridge to 300 m or more. East of the ridge, in the area upto river Yamuna, the alluvium thickness is comparatively less to about 165 m. East of river Yamuna covering parts of city and Shahadara blocks, the thickness ranges from 48 to 240 m in the Chattarpur basin of Mehrauli block the alluvial thickness from a few metres near the periphery to 115 m around Satbari bund.

2.2 Drainage:

The river Yamuna is the only perennial river flowing in the territory. Eastern and western Yamuna canals taking off from Tajewala and the Agra canal taking off from Okhla, are the three major canal system, originating from the river Yamuna. The eastern part of the area is drained by Yamuna river which are perennial entrenched meandering stream. Yamuna is however, braided also. Besides these, numerous small drains, nala and distributaries flow over the area. Agra canals are the important canals of the area which receive effluents of industries and domestic waste and finally drains into Yamuna river.

The river Yamuna is the main source of surface water in the capital territory which emerges from the hills near Tajewala and flows from north to south in the territory. It enters Delhi near Wazirabad and after flowing through the capital territory for about 48 kms enters Uttar Pradesh near Okhla. The river Sahbi from Haryana enters capital territory through Dhansa bund more or less as sheet flows. It first discharges into Najafgarh Jheel and then flows into river Yamuna through Najafgarh drain. Besides, the rain water generates run off which flows during monsoon through streams, nalas and drains. The streams have their well defined watersheds mostly in hard rocks in Delhi ridge area and Chattarpur basin.

The major surface water sources lie outside NCT of Delhi and the share of the surface water from the Himalayan rivers is through different interstate agreements. The share of surface water from these rivers as per interstate agreement is as follows:

1. Yamuna - 724 mcm
2. Ganga - 178.8 mcm
3. Bhakra water - 246.4 mcm

The river Yamuna provides the major share of surface water in the territory. Based on 75% dependability the notional virgin flow in the river Yamuna upto Okhla has been assessed as 11.70 billion cubic meters (BCM) and mean year availability has been assessed as 13.00 BCM. Seasonal allocation of annual utilizable flow of river Yamuna for NCT of Delhi are as follows:

(In mcm)

July-Oct	Nov-Feb	Marh-June	Annual
580	68	76	724

Out of 724 mcm water allocation, the monsoon run off is 580 mcm. As per the information available, nearly half of this flood water is not being utilized at present and flows out of Delhi.

Besides, the surplus flood flows in Yamuna during monsoon, the run off generated from rainfall is also available for utilization. The water flowing in the drains can be another surplus quantity for utilization. The drain water is mostly polluted due to disposal of sewage in these drains. And has not been considered at present. However, the drain water for the stretch of Najafgarh drain upstream of its confluence with Ganda Nala appears unpolluted and could be utilized for recharge of groundwater reservoir.

Considering the Yamuna flow and the run off generated during monsoon, the surplus monsoon run off availability works out to be as follows:

1.	Yamuna Surplus flood flow	-	282 mcm
2.	Rainfall run off	-	162 mcm
	Total	-	444 mcm

This surplus run off can be used for augmenting the groundwater resources.

2.3 Soil and Vegetation:

In the study area along Yamuna soil is very fertile. The surface soil is compact yellow silty clay or sandy clay which at certain places is calcareous nature. The western part of the Yamuna flood plain shows development of light brownish grey silt or sand over the surface. The entire area is under cultivation of different crops of Rabi, Kharif and hence natural vegetal growth is few and sparse. The different types of flora in the area are large trees like mango, peepal, neem, acacia, palm etc. The important crops grown in the study area wheat, gram, bajra, and Jowar. The important sources of irrigation are tubewells, wells, and canals.

2.4 Climate and Rainfall:

The area under investigation enjoys a typical semi-arid climate with a long and dry hot weather. The summer begins by the end of March and continues upto June. During April to June the heat is oppressive and dust storms of severe intensity are common. The area experiences severe cold during December and February when the minimum temperature reaches to 5°C.

The area receives southwest monsoon shower between July to September. The area also gets winter shower in the month of December and January. The precipitation of the area is erratic and uncertain. The southwestern monsoon accounts for most of the rainfall.

The normal rainfall in the territory is 611.8 mm. The rainfall increases from the southwest to northeast. About 81% of the annual rainfall is received during Pre-monsoon months of July, August and September. The rest of the annual rainfall is received as winter rains and as thunderstorm rain in the per and the post monsoon months. On an average, rain of 2.5 mm or more falls on 27 days in a year of these 19 days are during the monsoon months. Two to three days in June are rainy.

The annual average rainfall since 1980 to 1999 at Safdarjung, Palam and Delhi University stations is 760 mm, 732.16 mm, and 794.51 mm. The hourly intensity of rainfall in Delhi is 43.7 mm/hr in two years return period and about 20 to 25 mm in one-year return period. Recharge structure are designed for hourly intensity of rainfall in one years return period. The month wise break up of rainfall for NCT Delhi is as follows:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
a	14.5	13.2	9.9	5.5	9.2	38.8	191.6	197.4	105.3	19.3	2.8	4.3	611.8
b	1.2	1.0	0.8	0.5	0.8	2.1	7.4	7.9	4.0	0.8	0.1	0.4	

a - Normal rainfall in mm.

b - Average number of rainy days with rainfall of 2.5mm or more.

The precipitation over NCT of Delhi generates surface water run off through streams, drains and as sheet flow. Delhi being highly urbanized, the run off is high due to extensive paved area. Considering a run off, coefficient of 30% in urban areas and 12% in the other areas, the total surface run off works out to be 162 mcm. The major part of this run off generally contributes to the Yamuna flow in the mid and down stream part of the river.

The groundwater availability in NCT, Delhi is controlled by the hydrogeological situation characterized by occurrence of alluvial formation and quartzitic hard rocks. The hydrogeological set up and the following distinct physiographic units influence the groundwater occurrence:

(1) Alluvial plain on eastern and western sides of the ridge (low to moderate yield prospects, 25-30 m^3/hr).

(2) Yamuna flood plain deposits (large yield prospects, 50-100 m^3/hr).

(3) Isolated and nearly closed Chattarpur alluvial basin (low yield prospects, 10-15 m^3/hr).

(4) NNE-SSW trending Quartzite Ridge (low yield prospects, 5-10 m^3/hr).

Data reveals that in NCT, Delhi, the hydraulic conductivity of newer alluvium (fine to medium sand) spreading along the Yamuna River is varying between 40 to 70 m/day. The hydraulic conductivity of aquifers in older alluvium ranges between 7 to 24 m/day.

Chapter 3

Hydrogeology

HYDROGEOLOGY

Hydrogeology concerned primarily with the mode of occurrence, distribution, movement and chemistry of water occurring in sub-surface in relation to the geological environment. It forms the basis of all planning for development and utilization of water resources. Management and development of groundwater has become basically a social issue in global perspective as every fact of human society has a growing demand for water. The scenario of groundwater hydrogeology, therefore, would increasingly embrace prognostic approach on the quantity aspects within the framework of various inherent variables present in the heterogeneity of the interactive dynamic processes. As progressive improvements and refinements in hydrological techniques result in more reliable forecasts of runoff, recharge, floods and droughts, it becomes possible to make better plans and choices for development of water resources (Singh, 1997).

Hydrogeology is an emerging science. It is only recently that it has started finding its own niche in the geophysical arena. Until recent past it was more of an appendage of hydraulic engineering and its scope was confined to rather limited set of systems and paradigms, and its tools and techniques were mostly empirical (Singh, 1982). However, with growing environmental awareness on one hand and digital revolution on the other in appreciation for the role of hydrology in addressing critical environmental problems began to develop (Hipel et al., 1994).

During a span of nearly four decades hydrogeology has merged into a legitimate branch of geophysical science for the evaluation, analysis and management of groundwater. Nowadays there is increasing emphasis on applying the laws of science to solving hydrologic problems and verifying hydrologic theories using field or laboratory data.

Groundwater has now become the main sources of water supply because of increasing pollution of surface water. Groundwater in its natural state is invariably moving and movement of groundwater is influenced by the sequence, lithology, thickness and structure of the rock formation. The formation laws governing the movement of groundwater are the continuity equation and the Darcy flux law. When these coupled, the resulting equation is the governing equation for groundwater motion which is a parabolic partial differential equation (Freeze & Cherry, 1979). Depending upon the type of aquifer and assumptions made to simplify the geometric representation and the flow therein, the governing equation specializes into the Theis equation, poison equation, Boussinesq equation. Most of the advances made in groundwater hydrology are based on these equations.

3.1 Groundwater Utilization:

Groundwater development and utilization have increased immensely worldwide for irrigation, domestic and industrial purposes. The utilization of groundwater resources is therefore, of fundamental importance for the economic development of the area. With limited water resources ever-increasing population and simultaneous technological developments, the need for conservation, preservation and efficient utilization of available waters are nowadays being realized by all the concerned. Due to mismanagement of irrigated agriculture and certain misconceptions among farmers, many fertile lands have become water logged. Thus an efficient and scientific management of the irrigation water should become an essential part for all the planning and development works connected with water resources, to increase agricultural production necessary to meet food and water requirements of the fast growing population.

For a large proportion of the population of a region, water supplies rely moreover on drawing groundwater from a large number of wells and tubewells. Since the available groundwater resources alone of a region do not survive to satisfy the rapidly rising water requirements, long term hydrological planning envisages the extraction of large quantities of surface water.

India is gifted by nature with a large number of major rivers. There is an extreme disparity in distribution of water resources, spatially and temporally in these river basins due to unequal precipitation. The total utilizable groundwater potential of the country has been estimated as 43.2 m. ha/m/ year. After making provision for domestic industrial and other higher priority uses the potential available for irrigation is 36 m. ha/m/year. Taking the country as a whole, about 1/3rd of the potential is estimated to be utilized at present. Groundwater is the major source of water supplies for domestic, industrial and agricultural purposes in the study area. The surface water is contributed by Yamuna river and Agra canals.

The utilization of water both surface and sub-surface depends upon the groundwater resources of the area. With the establishment of industries and rapid increase in population, there is profound increase in the demand of water supply. The water from Yamuna, Agra and Hindon has been suggested as additional source of water supply. The use of groundwater alongwith Agra canals not only ensures steady supply to industries and cultivated fields on time but helps to reduce water logging and salinization due to consequent movement of surface water.

3.2 Hydrogeological Setting:

The Yamuna river sub-basin comprises the western part of Ganga basin which forms one of the most potential groundwater provinces of India. The alluvial plain of Ganga basin, occupies a structural trough or down warp of earth crust, the origin of which is related to plate tectonic and Himalayan uplift. The Ganga plain is made up of a thick pile of quaternary unconsolidated sediments comprising clay, silt, sand and kankar in varying proportions, and are known to contain good aquifers. The entire basin has been covered by systematic hydrogeological survey (Sharma and Sharma, 1973, Sinha 1980, Pathak 1982, Bajpai, 1983, Kakar, 1989, Chaturvedi et al., 1992 and Khanna, 1992).

The Ganga plain in Uttar Pradesh has been divided into four hydrogeologic units, viz., Bhabar, Terai, Central Ganga plain and Marginal Alluvial plain. The heavily sediment loaded treams on their emergence from the hills dump their load on a relatively flat area of northern fringe in Ganga plain resulting in the formation of alluvial fans at the foot hills. The continuation of this process and consequent coalescence formed the Bhabar zone. Groundwater in this deposits occurs under unconfined condition and water level is generally deep being more than 30 meters below land surface.

The deposits of Terai zone are distal sediments of the Bhabar fans which were washed down and sorted into distinct grain size associations. This zone comprises predominant clayey sediments with interrelated beds of sand and gravel, and is characterized by moist, swampy, gently undulating, south perennial drainages, which emanate from the springs and amalgamate down stream to form important rivers. The top aquifers in this zone are generally unconfined and the water level is normally within 4 m below land surface. There are localized occurrence of flowing condition with piezometric head varies between 6.6 and 8.9 m above the ground level.

The vast alluvial tract lying south of Terai and bounded in south by Yamuna forms the hydrogeological unit of the Central Ganga plain and is considered to be the most important groundwater resources potential of Uttar Pradesh. This belt is a plain of low relief and numerous fluvial depositional and erosional features. Depth to water level generally varies from 2 to 12 m below the land surface. Because of rapid change in their thickness and texture of granular zones, there is wide variation in permeability and transmissibility of the aquifers.

Marginal Alluvial plain is characterized by restricted thickness of alluvium over the basement. It occupies the area south of Yamuna in western Uttar Pradesh and south of Ganga river in eastern Uttar Pradesh and Bihar. The water level generally ranges from 2.5 m to 28 m below ground surface. The discharge of tubewells varies between 60 and 240 m/hour for draw down from 3 to 16 m.

3.3 Hydrogeological framework of the study area:

The study area occupying the parts of Yamuna river sub-basin covers mainly south Delhi and east Delhi. The quaternary alluvium comprising sands of various grades, clay and silt intercalated with kankar occupies the major part of the area and forms the potential groundwater reservoir. Groundwater occurs under semi-confined to unconfined conditions.

Kankar, silt, and fine sand horizons, found within the uppermost clay sequence permit storage and movement of groundwater to a limited extent. This zone forms the water table aquifer and support hundreds of tubewells in the area. The principal sources of recharge are rainfall, irrigation return flow, Yamuna river and Agra canals and numerous surface water bodies like ponds, lakes etc.

The growing population has put the water supply system under great stress. Delhi Jal Board has the current treatment capacity of 660 MGD and it is supplying water at the rate of 232 lpcd. Against this, the present requirement of water is about 800 MGD (for all uses) based on MPD-2001 norm of 363 lpcd for urban population and 100 lpcd for rural population. The contribution of raw water supply from different sources are as follows:

1.	Wazirabad Water Treatment Plant	120 MGD (Yamuna River)
2.	Chandrawal Water Treatment Plant	90 MGD (Yamuna River)
3.	Hyderpur Water Treatment Plant	200 MGD (Yamuna River)
4.	Bhagirathi Water Treatment Plant	100 MGD (Yamuna & Upper Ganga Canal)
5.	Nangloi Water Treatment	20 MGD (Western Yamuna Canal)
6.	Okhla & Direct Supply	130 MGD (Groundwater)

The water availability from surface water source viz. Yamuna, Ganga and Bhakra system is of the order of 1150.2 MCM. Though at present about 660 MGD of treated water is being released into the piped system, considering the 15% to 18% transit losses, actual quantity of potable water supplied to the consumer is around 550 MGD. Thus against the present water demand, the shortage is approximately 250 MGD. For future source, it is proposed that long term projects at Tehri Dam (160 MGD), Kishau Dam (370 MGD) and Renuka Dam (275 MGD) and to some extent groundwater source is confirmed for water supply in the near future. The Tehri dam project is under construction. As far as other three dams are concerned hardly any work has been started and as such no raw water supplies can be foreseen in the near future from these dams.

3.4 Groundwater Supply Scenario:

Groundwater is one of the sources of raw water for Delhi Jal Board. Groundwater is contributing about 130 MGD of water to water supply system and is being exploited through a battery of tubewells in Yamuna Flood Plain, Ranney wells in Yamuna Flood Plain and number of tubewells located in south and southwest districts of NCT, Delhi. Moreover, another 250 MGD of groundwater is being exploited by individual private tubewells so that to meet the demand-supply gap in water supply. Thus logically speaking, it is estimated that at present groundwater is supplying about 380 MGD of water i.e. about 48% of total water requirement.

Consequences of Indiscriminate Groundwater Exploitation:

Pre-monsoon depth of water levels during 2002 in NCT, Delhi could be divided into six zones i.e. <5 m, 5-10 m, 10-20 m, 20-30 m, 30-40 m and 40-50 meters below ground level. The deeper water levels i.e. in the range of 40 to 50 m bgl are found in parts of South district (Tughlakabad, Lado Sarai and Vasant Kunj areas). All along the Yamuna river and most parts of North-west district, water levels are shallow within 5 m bgl. In the central part of southwest district, water levels are in the range of 10 to 20 m bgl. In 1960's water levels in large part of NCT, Delhi were shallow, the shallowest depth to water level recorded was being 0.47 m bgl. By and large during 1960, the water level was within 4-5 and even in some parts water logged conditions existed necessitating pumpage of water to save the foundations of buildings in the area. During 1960 to 1977 the water levels declined by 2 m or less in most parts of Delhi. In the Central part of Southwest district (Najafgarh block) and southeastern parts of Chattarpur basin in South district a fall of 2-6 m was observed. This was mainly due to intensive groundwater development for irrigation. During 1977-1983 water table decline by 4 m or less in most parts of Delhi and rise being confined to small areas in northern Delhi and in the southern part of Chattarpur basin. In 1983 the depth to water level was about 10 m. bgl. in major parts of South Delhi with the deepest level being 26 m. below ground level at Mehrauli in South district. Parts of South district exhibited a fall of 4-8 m during 1977-83 due to increase pumpage for domestic purpose in residential areas and farm houses. Since w1983 water levels are declining all over the NCT, Delhi except a small area along Yamuna river where no decline in water level is observed.

Average Pre-monsoon Groundwater Levels in different districts of NCT, Delhi (m bgl).

Year	Northwest and West districts	North, Central and New Delhi districts	South district	Southwest district	East and Northeast districts
1960	2.00	5.00	10.00	2.00	2.00
1977	2.50	5.00	13.00	4.00	3.00
1983	4.00	5.00	15.00	6.00	3.00
1995	4.50	8.00	20.00	9.00	4.00
2000	5.90	11.63	24.05	10.47	5.50
2002	6.55	14.12	33.38	12.69	6.45

3.5 Hydrogeological Investigations:

Groundwater plays vital role in determining transmitting and water bearing capacity of geological formations. Hydrologic investigations are of two types; theoretical and applied (Singh, 1988, 1989). The former are those investigations that involve concepts, processes, postulates, theories and problems, and the later are those investigations that involve methods, techniques, modules, computers and GIS. In addition, there is another category of investigations that involve data acquisition management, storage and retrieval (Singh, 1997).

In order to study the hydrogeological condition including groundwater movement and changes in water level in response to rainfall, evaporation, groundwater use and other local factors, systematic well investigations of 11 observation tubewell and handpump (Table. 1) were carried out. The pre and post-monsoon water levels were measured in the tubewell and hand pump during pre-monsoon and post-monsoon, 2004.

The collected water level data were used in the preparation of depth to water level fluctuation showing in figure 3.

3.6 Occurrence of Groundwater:

Occurrence of groundwater in the deposits depend on the several factors such as size of the catchment, upstream of the cone and quantity of water discharged into deposits, shape of the cone structure, thickness, permeability of the deposits and the nature of the basement rocks. In the study area groundwater occurs in alluvium and the underlying weathered and jointed quartzites.

Alluvium deposits are highly porous and permeable because of the presence of sand and kankar. Groundwater occurs in the pore spaces of alluvial sediments in the zone of saturation. In alluvium, sand, silt and kankar from potential aquifer zones with generally occur within 40 to 50 metre depth.

Groundwater occurs under phreatic condition at shallow depth whereas at greater depth it occurs under confined condition.

There are four different hydrogeological environments viz. Alluvial plain on eastern and western sides of ridge, Yamuna flood plain, Chattarpur alluvial basin and quartzitic ridge control movement and occurrence of groundwater.

South area of NCT, Delhi is underlain by weathered and fractured quartzites. Thickness of unsaturated zone is about 40 metre, which can be utilized for recharging the aquifer system. Groundwater occurs in this zone is also very intensive resulting into substantial lowering of water levels in the past decade. The aquifer system lies at greater depth in the south western part and shallow depth in south eastern part of the study area.

3.7 Yield Characteristics:

Yield characteristics of an aquifer depends upon the porosity and permeability of the rock formation, which in turn depend upon grain size, shape and distribution of pores, compaction of the stratum and time of drainage. Fine grained material yield little water whereas coarse grained materials permit a substantial release of water and hand serve as good aquifers.

3.8 Depth to Water Level:

Depth to water level one of the most important and common measurement in groundwater investigation is the determination of the depth to groundwater aquifer, the water level in the upper surface of the zone of saturation where the pressure is atmospheric. Water level can be defined as the level at which water stands in wells penetrating the aquifer, just enough to hold standing water. However, the water level standing in dug wells are considered accurate enough to represent water level of an area. In existing dug wells in an area water level data are needed to define groundwater flow directions, regional variation in water levels over time and effects of pumping tests.

On the basis of water level data collected from eleven hydrographic stations scattered in the study area, during pre-monsoon and post-monsoon during May and Nov.-Dec. respectively depth to water level of pre- and post-monsoon period showing in Fig. 3.

3.8.1 Depth to Water Level (Pre-monsoon, May 2004):

A perusal of the depth of water level of pre-monsoon, 2004 (Table 11) reveals that the depth to water level in the area ranges from 10.30 m and 59.64 m below the ground level. Shallow depths to water level have been recorded in the Okhla head and Abul Fazal Enclave. Deep water levels occurred in South Delhi viz. Vasant Kunj, J.N.U., J.H.U., Vayusenabad, Vasant Vihar, Safdarjung Hospital and Pushp Vihar.

The maximum depth to water level was observed at Jamia Hamdard University (59.64 m bgl) in pre-monsoon.

3.8.2 Depth to Water Level (Post-monsoon, Nov.-Dec. 2004):

Depth to water level during post-monsoon period varied from 9.40 to 51.69 metre below ground level showing in Fig. 9. The areas where water level depth exceeded during post-monsoon period are J.N.U., J.H.U., Vayusenabad, Vasant Vihar, Safdarjung Hospital and Pushp Vihar. The comparison depth to water level showing in Fig. 3. There is an average increase of depth to water level 1.98 m bgl. Decreasing trends have been observed in depth to water level at Vasant Kunj about 1.34 m bgl.

3.8.3 Water Level Fluctuation:

Water level in an area fluctuates in responses to recharge and discharge from the aquifer system. Recharge takes place mainly due to precipitation as well as due to irrigation return flow. Excessive withdrawal of water from aquifer for domestic, industrial and irrigational needs and evapo-transpiration is responsible for water level fluctuation. Fluctuations in water levels indicate both changes in the actual quantity of water stored in aquifers and movement of groundwater. The amount of water taken from or added to storage per unit change in water levels in unconfined aquifers is many times larger than in confined aquifer.

Based on water level depth data collected during pre- and post-monsoon period for one year (2004), water level fluctuation (Fig. 3) indicating different fluctuation zones. It is observed that the quantum of seasonal fluctuation in water level varies from 1.0 to 3.59 m bgl in the year 2004.

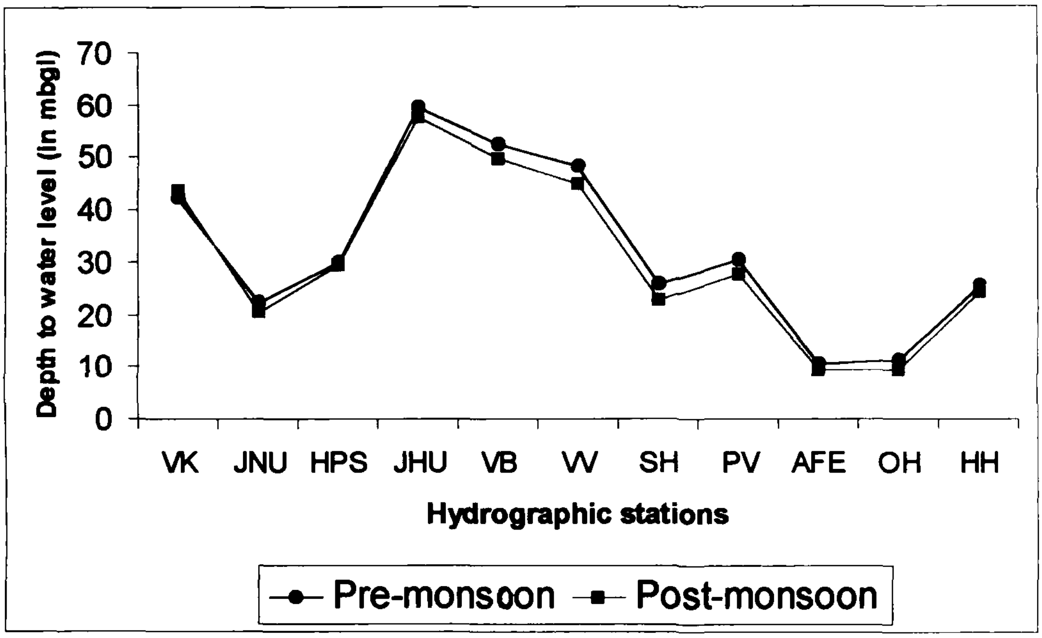
3.8.9 Movement of Groundwater:

Groundwater is in constant motion from a point of recharge to a point of discharge in accordance with the laws governing flow of fluids in porous media. Water within the ground moves downward through the unsaturated zone under the action of gravity, whereas in the saturated zone it moves in a direction determined by the surrounding hydraulic situation. In general groundwater moves in the direction of slope of water table and the slope of water table in turn depends on permeability and thickness of water bearing zone, topography, lithology and local variations in the quantity of recharge and discharge.

Table 1: Hydrogeological data of depth to water level in the study area (2004)

S.No.	Hydrographic station	Depth to water level (in mts bgl), Pre-monsoon May 2004	Depth to water level (in mts bgl), Post-monsoon Nov.-Dec. 2004	Fluctuation
1.	Sultanj Ghari's Tomb, Vasant Kunj	42.34	43.68	1.34
2.	Jawaharlal Nehru University	22.28	20.46	1.82
3.	Hamdard Public School, Talimabad	30.00	29.69	0.31
4.	Jamia Hamdard University, Hamdard Nagar	59.64	57.69	1.95
5.	Vayusenabad, Khanpur	52.38	49.85	2.53
6.	Vasant Vihar	48.43	44.84	3.59
7.	Safdarjung Hospital	25.69	22.73	2.96
8.	Pushp Bhawan, Pushp Vihar	30.33	27.64	2.69
9.	Abul Fazal Enclave	10.30	9.30	1.00
10.	Okhla Head	11.40	9.40	2.00
11.	Hotel Hayat	25.46	24.49	1.00

Figure – 3



Fluctuation graph of pre and post-monsoon showing depth to water level (in mbgl).

Vasant Kunj (VK),
Jawaharlal Nehru University (JNU)
Hamdard Public School (HPS)
Jamia Hamdard University (JHU)
Vaysenabad (VB)
Vasant Vihar (VV)
Safdarjung Hospital (SH)
Pushp Bhawan (PB)
Okhla Head (OH)
Hotel Hayat (HH)

Chapter 4

Artificial recharge techniques and its impact on groundwater quality and water level

ARTIFICIAL RECHARGE TECHNIQUES AND ITS IMPACT ON WATER QUALITY AND WATER LEVEL

Management and Development Strategy:

Nuclear research laboratory, Indian Agricultural Research Institute (IARI) has estimated direct groundwater recharge from the rainfall based on groundwater ^{18}O-Cl relationships. Groundwater recharge from direct infiltration of rainfall shows a wide range (0.2 to 66.0%) of spatial and temporal variation, with most parts receiving less than 8% recharge from rainfall.

Groundwater recharge from rainfall in Delhi area.

- Alipur Block 2.0 – 50.0%
- Khanjhawla Block 0.3 – 7.0%
- Najafgarh Block 0.2 – 66.0%
- Mehrauli Block 3.0 – 33.0%
- Shahadara Block 3.0 – 18%
- City Block 3.0%

Recharge from high intensity rainfall contributing flood is not a rapid process, but occurs through stagnant pools that are left in low lying areas after significant amount of surface runoff from the surrounding areas and farm lands. Thus, rainfall recharge being depression focused, certain parts of groundwater recharge zones may never receive direct infiltration to the water table. There is a need to conserve this large amount of water which can be utilized for artificial recharge to groundwater. The dynamic groundwater resources have been assessed as 292 MCM and present withdrawal is 312 MCM. The excessive withdrawal of groundwater is mainly in South, Southwest, New Delhi and Central districts and resulted into declining groundwater table to the tune of about 35 m in some parts during the last four decades. The annual precipitation over NCT, Delhi in volumetric terms comes out to be 910 MCM. The amount of runoff generated out of this is about 193 MCM. Thus it is essential to conserve each and every drop of water falling on the territory so as to solve the problem for water supply through augmentation of groundwater resources in suitable areas of the territory.

Urban centres in India are facing an ironical situation today. On one hand there is the acute water scarcity and on the other, the streets are often flooded during the monsoons. This has led to serious problems with quality and quantity of groundwater. This is despite the fact that all these cities receive good rainfall. However, this rainfall occurs during short spells of high intensity. Most of the rainfalls in just 100 hours out of 8,760 hours in a year. Because of such short duration of heavy rain, most of the rain falling on the surface tends to flow away rapidly leaving very little for recharge of groundwater. Most of the traditional water harvesting systems in cities have been neglected and fallen into disuse, worsening the urban water scenario. One of the solutions to the urban water crisis is **rainwater harvesting** (capturing the runoff).

This is practiced on a large scale in cities like Chennai, Bangalore and Delhi where rainwater harvesting is a part of the state policy. Elsewhere, countries like Germany, Japan, United States, and Singapore are along adopting rainwater harvesting. Rainwater harvesting helps in utilizing the primary source of water and prevent the runoff from going into sewer or storm drains, thereby reducing the load on treatment plants. Recharging water into the aquifers help in improving the quality of existing groundwater through dilution.

Broadly rainwater can be harvested for two purposes.

- Storing rainwater for ready use in containers above or below ground.
- Charge into the soil for withdrawal later (groundwater recharging)

Rainwater harvesting can be harvested from the following surfaces.

If buildings with impervious roofs are already in place, the catchment area is effectively available free of charge and they provide a supply at the point of consumption i.e. Landscape, open fields, parks, storm water, drains, roads and pavements and other open areas can be effectively used to harvest the runoff. The main advantage in using ground as collecting surface is that water can be collected from a larger area. This is particularly advantageous in areas of low rainfall. The potential of lakes, tanks and ponds to store rainwater is immense. The harvested rainwater cannot only be used to meet water requirements of the city, it also recharges groundwater aquifers.

Most of the residential colonies have proper network of storm water drains. If maintained neatly, these offer a simple and cost effective means of harvesting rainwater. For example, Delhi, where the total annual rainfall occurs during 3 or 4 months, is example of place where groundwater recharging is usually practiced.

4.1 Artificial Recharge:

Artificial recharge to groundwater is a process by which the groundwater reservoir is augmented at a rate of exceeding that obtaining under natural condition of replenishment. Any manmade scheme or facility that adds water to an aquifer may be considered to be an artificial recharge system.

The concept of rainwater harvesting is capturing the rainwater where it falls. Though Delhi receives normal rainfall of 611.8 mm in 27 rainy days, most of which is going waste as runoff (about 193 MCM). This can be tapped and stored in both surface and sub-surface reservoirs for which ample space is available in Delhi. The present availability from surface water sources is about 1150 MCM out of which 724 MCM water is available from river Yamuna. Out of this, 724 MCM, the monsoon runoff is 580 MCM. About half of this runoff i.e. 282 MCM will go as wastage. This added to 193 MCM surface runoff generated from rainfall on NCT, Delhi makes about 475 MCM and can be used for recharging the aquifer system.

Areas feasible for artificial recharge to groundwater has been demarcated based on the depth to water level and showing decline trend in water levels. The areas where water level is more than 8 m below ground level and showing continuously declining trend are identified as most suitable areas for taking up artificial recharge to groundwater. The deeper water levels are found in South district, thickness of unsaturated zone in Tughlakabad, Okhla, Khanpur, Pushp Vihar, Sainik Farm, Saket, Mehrauli, Lado Sarai and surrounding areas of Gadaipur, Jaunapur and Gittorni villages of south district varies from 35 to 40 m. In areas like Greater Kailash-I & II, Chittaranjanpark, Green Park and surrounding areas the thickness of unsaturated zone is about 25 m. In Vasant Kunj, Vasant Vihar, Samalkha and Rajokri areas of South west district has unsaturated zone thickness ranging from 30 to 40 m. In central part of South west district has unsaturated zone of about 12 to 15 m. In North west district thickness of unsaturated zone in Narela area is about 6 to 10

m. Thus very potential unsaturated aquifer system is available in NCT, Delhi to be utilized for recharging.

4.2 Application of Rainwater Harvesting:

1. Surface water is inadequate to meet our demand and we have to depend on groundwater.
2. Due to rapid urbanization infiltration of rainwater into the subsoil has decreased drastically and recharging of groundwater has diminished.
3. Over exploitation of groundwater resource has resulted decline in water level in most part of the area.
4. To enhance availability of groundwater at a specific place and time.
5. To arrest sea water ingress.
6. To improve the water quality in aquifer.
7. To improve the vegetation cover.
8. To raise water levels in wells and bore wells that are drying up.
9. To reduce power consumption.
10. Prevents chocking of storm water drains and reduces flooding of roads.
11. Saves energy required for lifting the groundwater.

4.3 Engineering design considerations of selected case studies of rainwater harvesting in urban areas:

Artificial Recharge to Groundwater in an area is based on hydrogeological characters of the area like soil cover, Nature of aquifer system at shallow depths, Depth to water level, rainfall pattern, groundwater development and rate of groundwater levels decline. Design of recharge techniques of an area need to taken into consideration of all above factors. Based on hydrogeological characters of Delhi and surrounding areas (Noida, Greater Noida, Ghaziabad, Meerut, Faridabad, Gurgaon and Bahadurgarh districts) is divided into six zones. These are:

1. Newer alluvium (Yamuna Sand) with water levels more than 8 m.
2. Older alluvium where water levels are 8 to 20 m with unsaturated zone of silty sand mixed with kankar.
3. Older alluvium where water levels is in between 20 to 35 m bgl.
4. Older alluvium with water levels 40 to 50 m bgl.
5. Hard rock at shallow depths under the alluvium of 10 to 15 m depth.
6. Hard rock from surface itself.

4.3.1 Area underlain by Newer Alluvium (Grey coloured Sand and Silt mixed with gravel and water level is 8 m to 20 m below ground level: Areas falling in this category are – Vasundhara Enclave, Preet Vihar, Vivek Vihar areas of East Delhi, Narela-Singhola areas of North Delhi. The area is underlain by Newer alluvium (Yamuna Sand) consists of mainly sand and silt down to a depth of about 30 to 50 m below ground level. Discharge of shallow tubewells in this zone varies from 500 to 600 liters per minute. Groundwater quality is generally fresh down to a depth of 30 to 40 m below which groundwater is brackish to saline in nature. In trans-Hindon area groundwater is fresh at all depths.

Recharge Structures Recommended: Pits with auger holes filled with gravel in the areas where water logging is taking place, Recharge pits with shallow recharge wells of 100 to 150 mm dia with depths of 15 to 20 m, Shafts of 6 to 8 m depth, Shafts of 4 to 5 m depth with recharge wells of 15 to 20 m where water levels are deep, recharge trenches with recharge wells (one, two or three based on the available runoff in the drains), abandoned tubewells, dugwells and handpumps.

4.3.2 Areas underlain by Older alluvium consists of silt, silty sand, clay mixed with kankar and water levels are in between 8 to 20 m bgl: Areas falling in this zone are:

(A) Connaught Place, Lodhi Garden, Parts of Lutyen Delhi, Karol Bagh, IARI Pusa.

(B) Parts of Southwest district (Dwarka, Najafgarh and rural areas of Najafgarh).

(C) Parts of West and Northwest districts (Janakpuri, Uttam Nagar, Vikaspuri, Parts of Rohini, Rajagarden, Tilak Nagar areas).

The area is underlain by predominantly silt and silty sand mixed with kankar at shallow depths followed by clay with kankar at deeper levels. Depth to water levels are in between 10 to 20 m bgl. Groundwater is generally fresh at shallow depths. Tubewells constructed down to a depth of about 40 m bgl are yielding about 300 lpm of water.

Recommended Recharge Structures: Recharge pits with borewells filled with gravel, Recharge shafts with bores and recharge tubewells, Lateral trenches with one tubewell or series of tubewells, Percolation ponds, Revival of Village tanks, Johads in association with recharge bores and shafts filled with filter material.

4.3.3 Areas underlain by Older alluvium consists of silt, silty sand, clay mixed with kankar and water levels are in between 20 to 35 m bgl: Areas falling in this zone are:

1. Central Parts of Chattarpur Basin, Gadaipur, Ghittorni and surrounding areas.
2. Parts of South districts – AIIMS, Safdarjung Hospital, Green Park, Hauz Khas and Malvia Nagar.

The area is underlain by predominantly sand of fine to medium grained and silt mixed with kankar at shallow depths followed by clay with kankar at deeper levels. Depth to water levels are in between 20 to 35 m bgl. Groundwater is generally fresh at 11 depths. Tubewells constructed down to a depth of about 70 to 90 m bgl are yielding about 300 to 350 lpm of water.

Recommended Recharge Structures: Recharge pits with borewells of depth 30 to 35 m filled with gravel for individual houses of 200 to 400 sq.m., Recharge shafts with bores and recharge tubewells of depth 30 to 35 m, Lateral trenches with one tubewell or series of tubewells, percolation ponds, revival of village tanks, Johads in association with recharge bores and shafts filled with filter material.

4.3.4 Areas underlain by Older alluvium consists of sand and silt mixed with kankar and clay with water levels are in between 40 to 55 m bgl: Areas falling in this zone are:

1. Areas along the Mehrauli-Badarpur Road.
2. Tughlakabad, Pushp Vihar, Lado Sarai and Saket.

The area is underlain by predominantly silty sand mixed with clay and kankar. Depth to hard rock is about 50 to 70 m below ground level. Substantially thick unsaturated zone is present in this area which can be utilized for recharging the aquifer system. Groundwater development in this zone is very intensive resulting into substantial lowering of water levels in the past decade.

Recommended Recharge Structures: Recharge pits with borewells of depth about 50 m filled with gravel for individual houses of 200 to 400 sq. m. Recharge shafts with bores and recharge tubewells of depth 40 to 50 m, Lateral trenches with one tubewell or series of tubewells, Recommended diameter of recharge tubewell is 100 mm dia. Recharge through abandoned tubewells and dugwells is most ideal in this environments.

4.3.5 Areas underlain by Older alluvium of depth 10 to 20 m followed by weathered and fractured quartzite with water levels varying between 20 to 30 m bgl: Areas falling in this zone are:

1. Fringe areas of Delhi Ridge.
2. Parts of C.R. Park and Kalkaji.
3. Northern part of Connaught Place, Rajendra Nagar and parts of Karol Bagh area.
4. Parts of Vasant Vihar

The area is underlain by predominantly older alluvium of depth varying between 10 to 20 m consists of predominantly Silty Sand mixed with kankar. Depth to water level is about 20 to 30 m below ground level. Thickness of unsaturated zone is about 25 m, which can be utilized for recharging the aquifer system. Groundwater development in this zone is also very intensive resulting into substantial lowering of water levels in the past decade.

Recommended Recharge Structures: Recharge pits with borewells of depth about 20 m filled with gravel for individual houses of 200 to 400 sq. m., Recharge Shafts with bores and recharge tubewells of about 30 to 35 m depth. Lateral trenches with one tubewell or series of tubewells, Recharge through abandoned tubewells and dugwells, Nala bunds and Gabion structures in small nalas of ridge area.

4.3.6 Areas underlain by weathered and fractured quartzite with water levels varying between 20 to 30 m bgl: Area falling in this zone are:

1. Delhi ridge extending from Kamala Nehru Ridge to Southern ridge.
2. Vasant Kunj, Parts of vasant Vihar.
3. Okhla Industrial Area, Nehru Place, Parts of C.R. Park.
4. Parts of Vasant Vihar.

The area is underlain by weathered and fractured quartzite. Depth to water level is about 20 to 50 m below ground level. Thickness of unsaturated zone is about 40 m, which can be utilized for recharging the aquifer system. Groundwater development in this zone is also very intensive resulting into substantial lowering of water levels in the past decade.

Recommended Recharge Structures: Recharge pits with borewells of depth about 40 m filled with gravel for individual houses of 200 to 400 sq. m., Recharge Shafts with bores and recharge tubewells of about 40 to 50 m depth. Lateral trenches with one tubewell or series of tubewells, Recharge through abandoned tubewells and dugwells, Nala bunds and Gabion structures in small nalas of ridge area, Percolation tanks and ponds with recharge wells.

In the study area salient features of recharge scheme are as follows:

1. Salient Features of Vayusenabad Recharge Scheme

1.	Total campus area	19 hectare
2.	Normal Monsoon runoff	612 mm
3.	Depth to water level	45 m bgl
4.	Estimated availability of runoff	18190 cu.m
5.	Recharge structures proposed	Four recharge trenches with tubewells
6.	Total cost of the project	5.41 lakhs
7.	Average life of the project	20 years
8.	Cost per 1000 lts. Recharge	1.75 rupees
9.	During the monsoon season of 2002, it is observed about 7463 cu.m. of runoff has been generated by 262 mm rainfall.	
10.	This has resulted into rise in water level of 3.65 m in the Vayusenabad.	
11.	Discharge of tubewells located about in this colony has increased to 300 to 350 lpm which sustained for 15 to 20 days after each storm.	

2. Salient Features of Vasant Vihar, D-Block Recharge Scheme

1.	IN this project runoff from the D block going waste through drains and surface flow on roads has been utilized and diverted into a park where three recharge structures were constructed.
2.	One abandoned tubewell has been utilized in this project.
3.	Total area contributing runoff: 36375 sq. m.
4.	Normal monsoon rainfall 611.8 mm
5.	Geological formation alluvium upto 10 m followed by quartzite.
6.	Depth to water level: 28-32 m bgl.
7.	Water available for recharge: 9400 cu.m.
8.	Recharge structures – Recharge through abandoned tubewell.
9.	Trench with tubewells: 2 nos.

3. Salient Features Recharge Scheme Grand Hyat Hotel, Vasant Kunj Phase-II (Fig. 8)

1.	Total area	4000 sq.m.
2.	Normal rainfall	794 mm
3.	Geological formation	Weathered and fractured quartzite
4.	Depth to water levels	25.46 m bgl
5.	Water available for recharge	13528 cu.m.
6.	*In this project existing sumps which have been constructed to pump* out storm water were converted into recharge shafts with tubewells	
7.	Seven recharge structures were constructed 3 existing sumps	
8.	Four recharge trenches with tubewells	
9.	Total cost of the project; 4 lakh rupees	
10.	Cost o recharging 1000 liters of water: 1.5 rupees	

4. Salient Features of Jamia Hamdard University Recharge Scheme (Fig. 7)

1.	Location	Tughlakabad
2.	Total area	3,15,380 sq.m.
3.	Volume of water annually harvested	674.0 lakh litre
4.	Depth to water level	59.64 m bgl
5.	Water harvested from (catchments)	Rooftops, Paved area, Unpaved area and Roads
6.	Types of structures	Recharge well with desilting chambers
7.	Total project cost	Rs. 6.25 lakh

5. Salient Features of Shri Ram School Recharge Scheme

1.	Location	Vasant Vihar
2.	Total area	6000 sq.m.
3.	Volume of water annually harvested	18.90 (lakh litres)
4.	Depth to water level	48.43 m bgl
5.	Water harvested from (catchments)	Rooftops
6.	Type of structures	Recharge well
7.	Total project cost	Rs. 1.25 lakh

4.4 Artificial Recharge Methods in the Study Area:

Rooftop rainwater harvesting is the technique of collection of rainwater from the roofs of the building and its storage at surface or in sub-surface aquifer, before it is lost as surface runoff. The augmented resource can be harvested in the time of need. Most urban residential, recreational, Institutional and commercial set ups have existing rainwater pipes. These pipes can be connected to direct the rooftop rainwater to the surface or sub-surface reservoir through simple and low cost techniques.

4.4.1 How much water can be collected?

The rainfall that can be collected may be calculated with the following formula:

Runoff = Catchment area x Runoff coefficient x Rainfall

Considering runoff coefficient of cemented roofs as 80%, even 10 mm of rainfall on 100 sq.m. or roof area will yield 800 liters of water. Availability of rainwater through rooftop rainwater harvesting showing in table 6.

Recharge to groundwater is a new concept of rainwater harvesting and the structures generally used are: The methods of groundwater recharge mainly are:

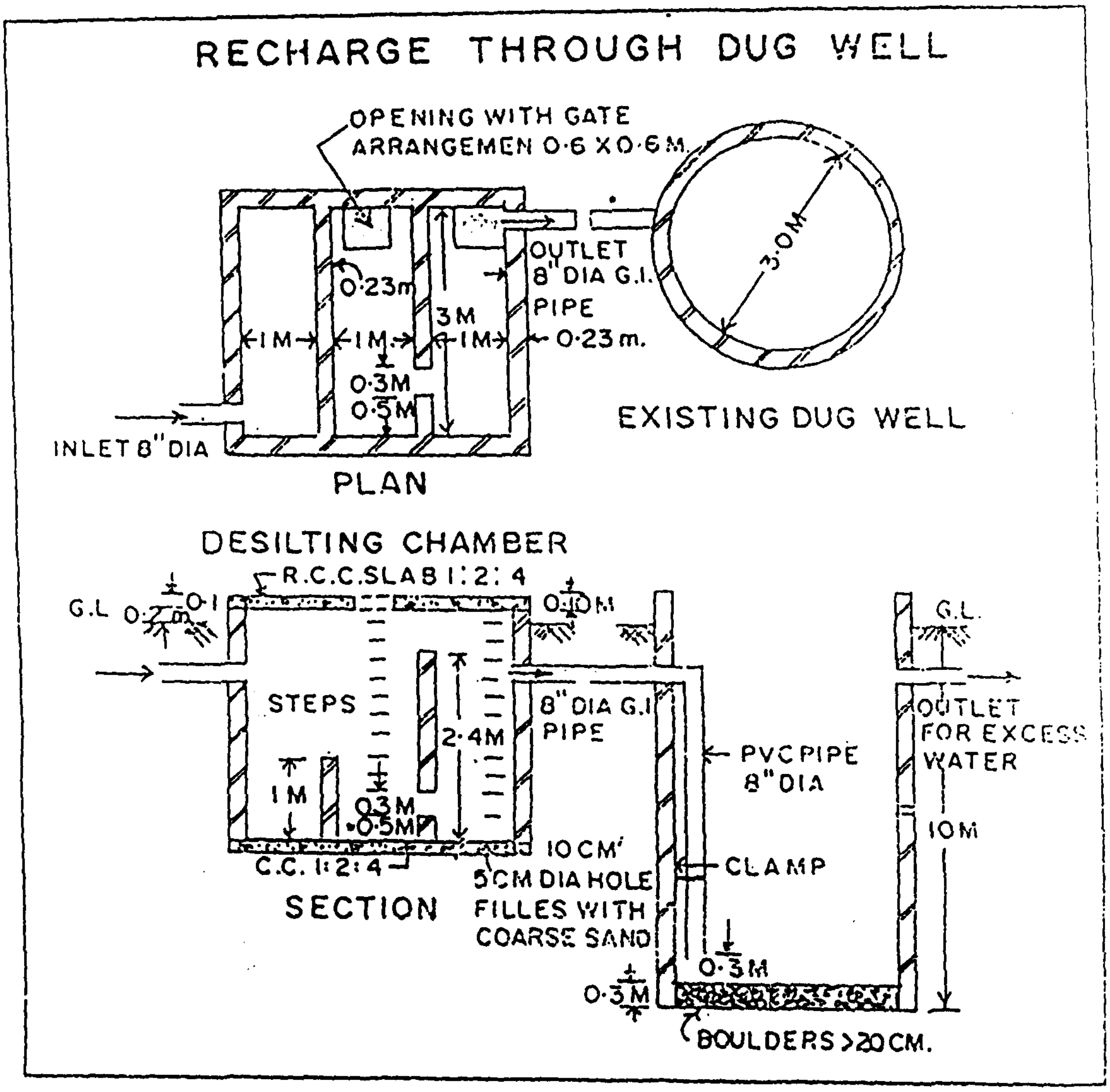
In Urban Areas: Rainwater harvesting through

4.4.2 Existing tubewells: In areas where the shallow aquifers have dried up and existing tubewells are tapping deeper aquifer rooftop rainwater harvesting through existing tubewell can be adopted to recharge the deeper aquifers. The recharge water is guided through online filter to the tubewell. The filter may be made of PVC pipe or any local material and is divided into three chambers by screens. The first chamber is filled up with gravel (6-10 mm), middle chamber with pebbles (12-20 mm) and last chamber with bigger pebbles (20-40 mm). If the roof area is more, a filter pit may be provided. Rainwater from roof is taken to collection/desilting chambers located on ground The pit may be of varying shapes or size depending upon the availability of runoff and are back-filled with graded material, boulder at the bottom, gravel in the middle and coarse sand at the top with varying thickness (0.30-0.50 m). Showing in Fig. 11.

4.4.3 Through Dugwells: The recharge water is guided through a pipe to the bottom of well or below the water level to avoid scouring of bottom and entrapment of air bubbles in the aquifer. Recharge water should be silt free and for removing the silt content, the runoff water should pass either through a desilting chamber or filter chamber. The bottom of the well should also be cleaned to make it silt free. Periodic chlorination should be done for controlling the bacteriological contaminations. Showing in Fig. 4.

4.4.4 Through Handpump: Water is diverted from rooftop to the handpump through pipes of suitable diameter. The recharge water should be silt free. An online filter may also be used if required. For running handpump, a closing valve is fitted in conveyance system near handpump to avoid entry of air in suction pipe. During recharging period, the water

Figure-4.



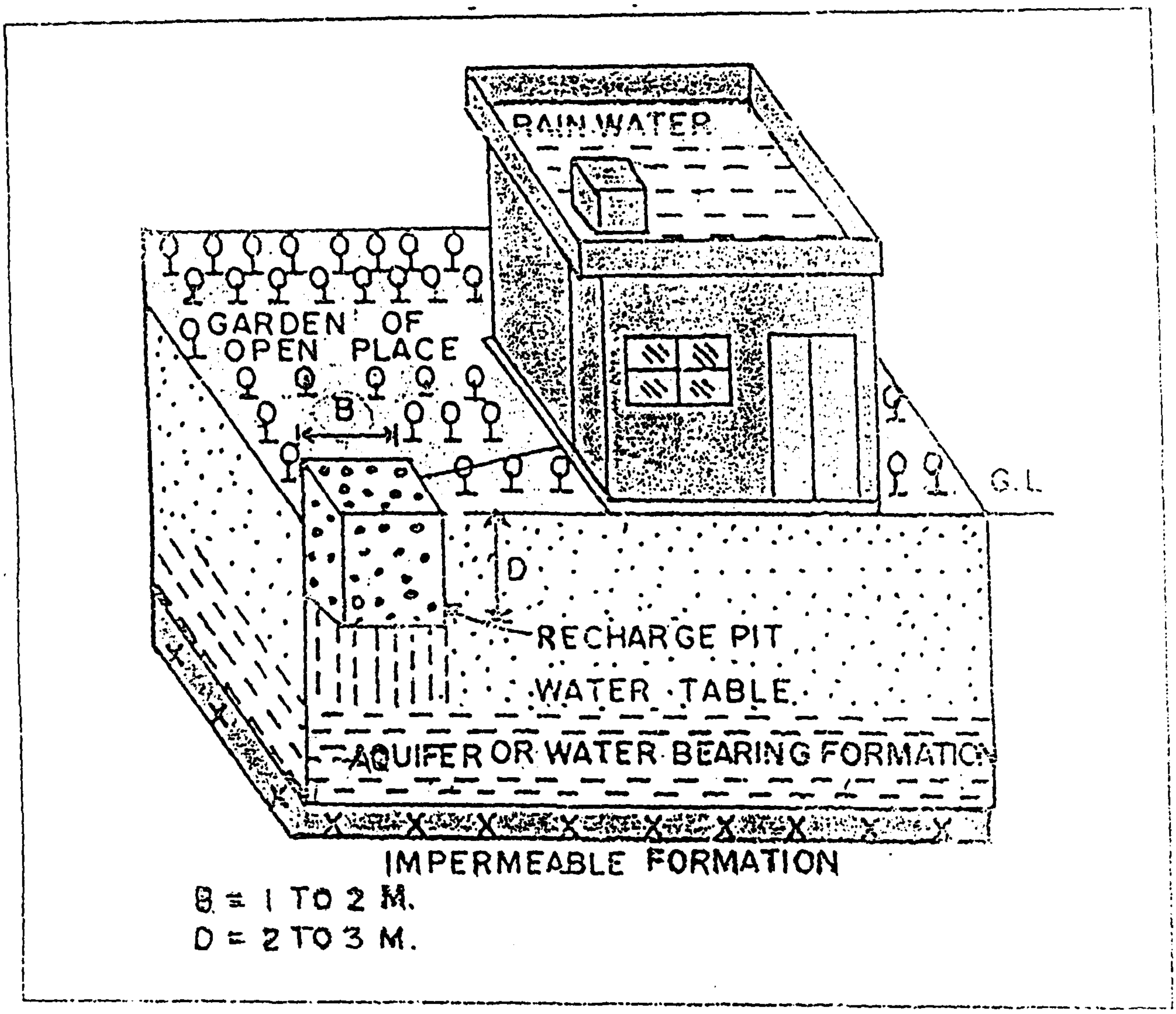
RECHARGE THROUGH DUG WELL
OPENING WITH GATE
ARRANGEMEN 0·6 X 0·6 M.
OUTLET
8" DIA G.I.
PIPE
0·23m
3M
1 M
1 M
1 M
0·23 m.
0·3M
0·5M
3·0M
INLET 8" DIA
PLAN
EXISTING DUG WELL
DESILTING CHAMBER
R.C.C.SLAB 1: 2: 4
G.L
0·1
0·10M
G.L.
STEPS
2·4M
8" DIA G.I
PIPE
OUTLET
FOR EXCESS
WATER
PVC PIPE
8" DIA
1 M
0·3M
0·5M
10 CM'
C.C. 1:2:4
5CM DIA HOLE
FILLES WITH
COARSE SAND
CLAMP
10 M
SECTION
0·3M
0·3M
BOULDERS >20 CM.

abstracted should be utilized after proper chlorination. It is suitable for small buildings having roof area upto 50 sq.m.

4.4.5 Through Recharge Pit: In alluvial areas where permeable rocks are exposed on the land surface or at very shallow depth, rooftop rainwater harvesting can be done through recharge pits. The technique is suitable for buildings having a roof area of 100 sq.m. and are constructed for recharging the shallow aquifers. Recharge Pits may be of any shape and size and are generally constructed 1 to 2 m. wide and 2 to 3 m. deep which are back filled with boulders (5-20 cm), gravels (5-10 mm) and coarse sand (1.5-2 mm) in graded form – Boulders at the bottom, gravels in between and coarse sand at the top so that the silt content that will come with runoff will be deposited on the top of the coarse sand layer and can easily be removed. For smaller roof area, pit may be filled with broken bricks/cobbles. Showing in Fig. (5a & 5b).

4.4.6 Through Recharge Trench: Recharge trenches are suitable for buildings having roof area of 200-300 sq.m. and where permeable strata is available at shallow depths. Trench may be 0.5 to 1 m wide, 1 to 1.5 m deep and 10 to 20 m long depending upon availability of water to be recharged and backfilled with boulders, gravels and coarse sand. Showing in Fig. 6.

Figure-5(a).



Recharge Pit

Figure-5(b). Recharge Pit

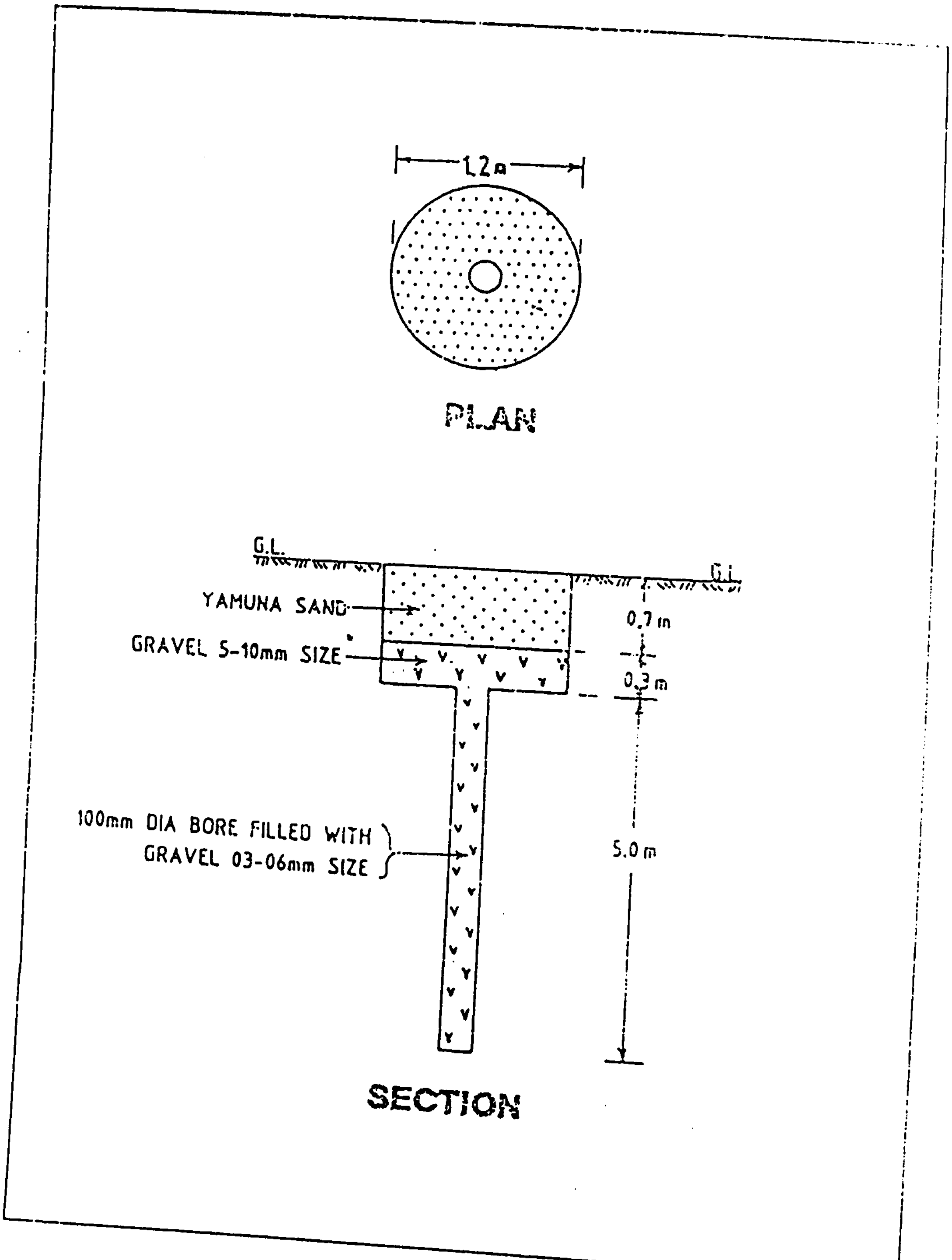
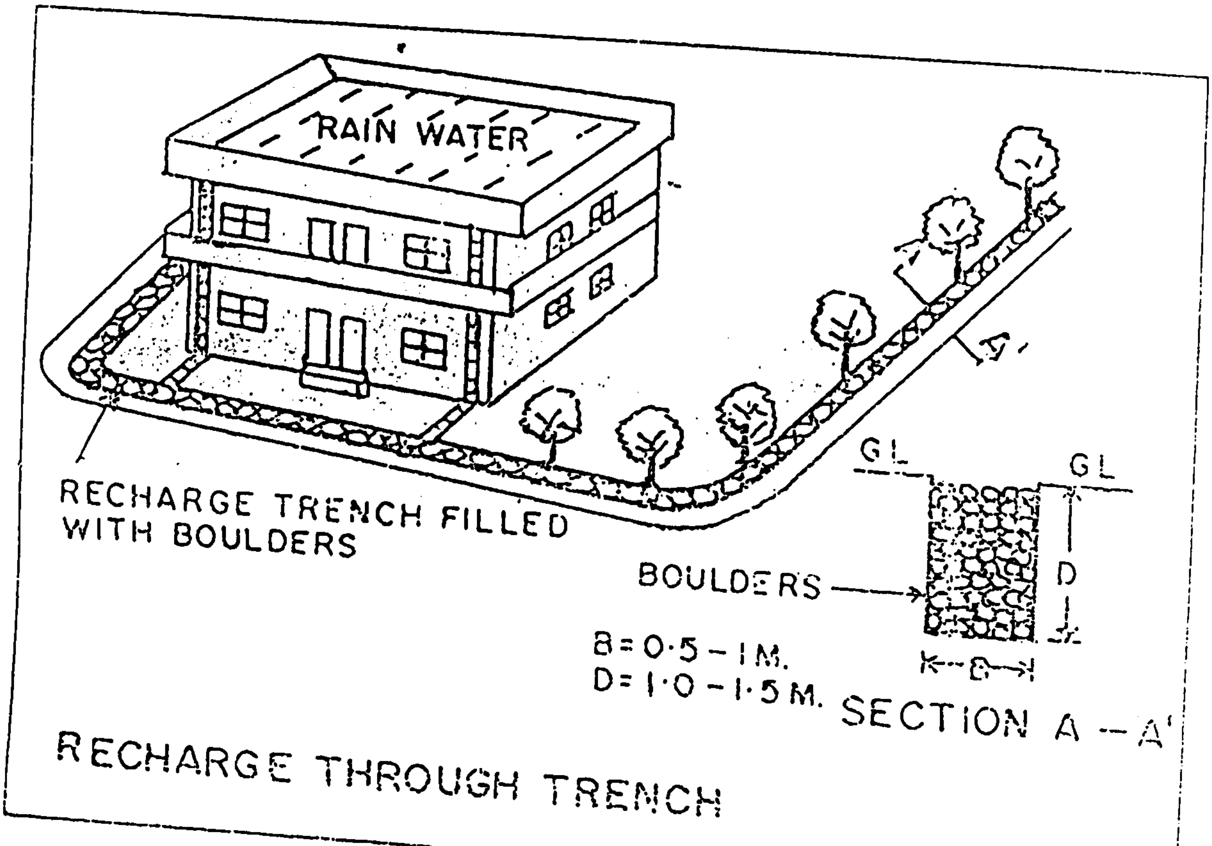


Figure-6.



Recharge Through Trench

4.4.7 Through Trench With Recharge Wells: In areas where the surface soil is impervious and large quantities of roof water or surface runoff is available within a very short period of heavy rainfall, the use of trench/pits is made to store the water in a filter media and subsequently recharge to groundwater through specially constructed recharge wells. This technique is ideally suited for area where permeable horizon is within 3 m below ground level. Recharge well of 100-300 mm diameter is constructed to a depth of at least 3 to 5 m below the water level. Based on the lithology of the area well assembly is designed with slotted pipe against the shallow and deeper aquifer. A lateral trench of 1.5 to 3 m with and 10 to 30 m length, depending upon the availability of water is constructed with the recharge well in the center. The number of recharge wells in the trench can be decided on the basis of water availability and local vertical permeability of the rocks. The trench is backfilled with boulders, gravels and coarse sand to act as a filter media for the recharge wells. If the aquifer is available at greater depth say more than 20 m, a shallow shaft of 2 to 5 m diameter and 3-5 metres deep may be constructed depending upon availability of runoff. Inside the shaft a recharge well of 100-300 mm dia. is constructed for recharging the available water to the deeper aquifers. At the bottom of the shaft a filter media is provided avoids choking of recharge well.

Figure-7.

Recharge Shaft with Tubewell at Jamia Hamdard School Talimabad

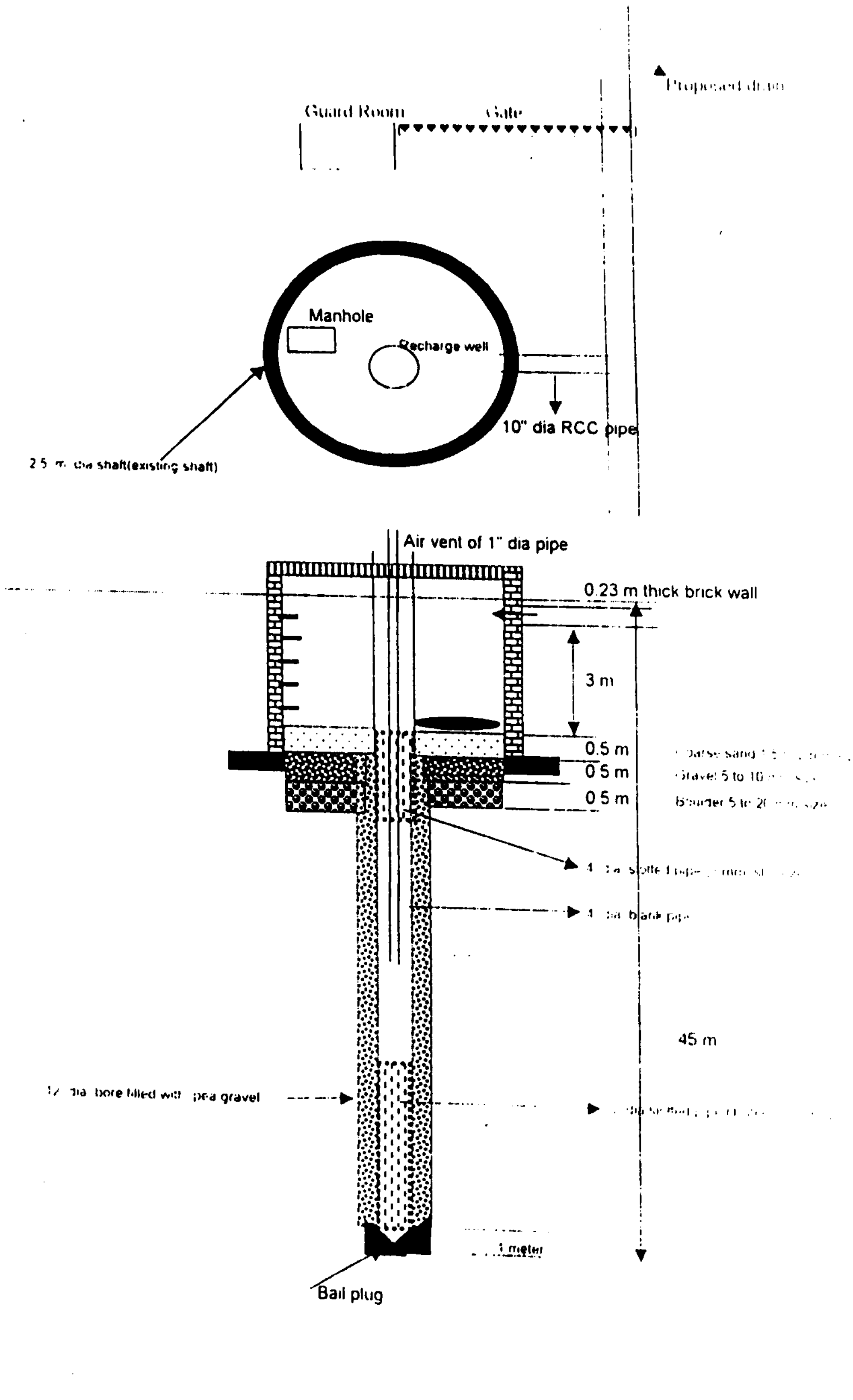
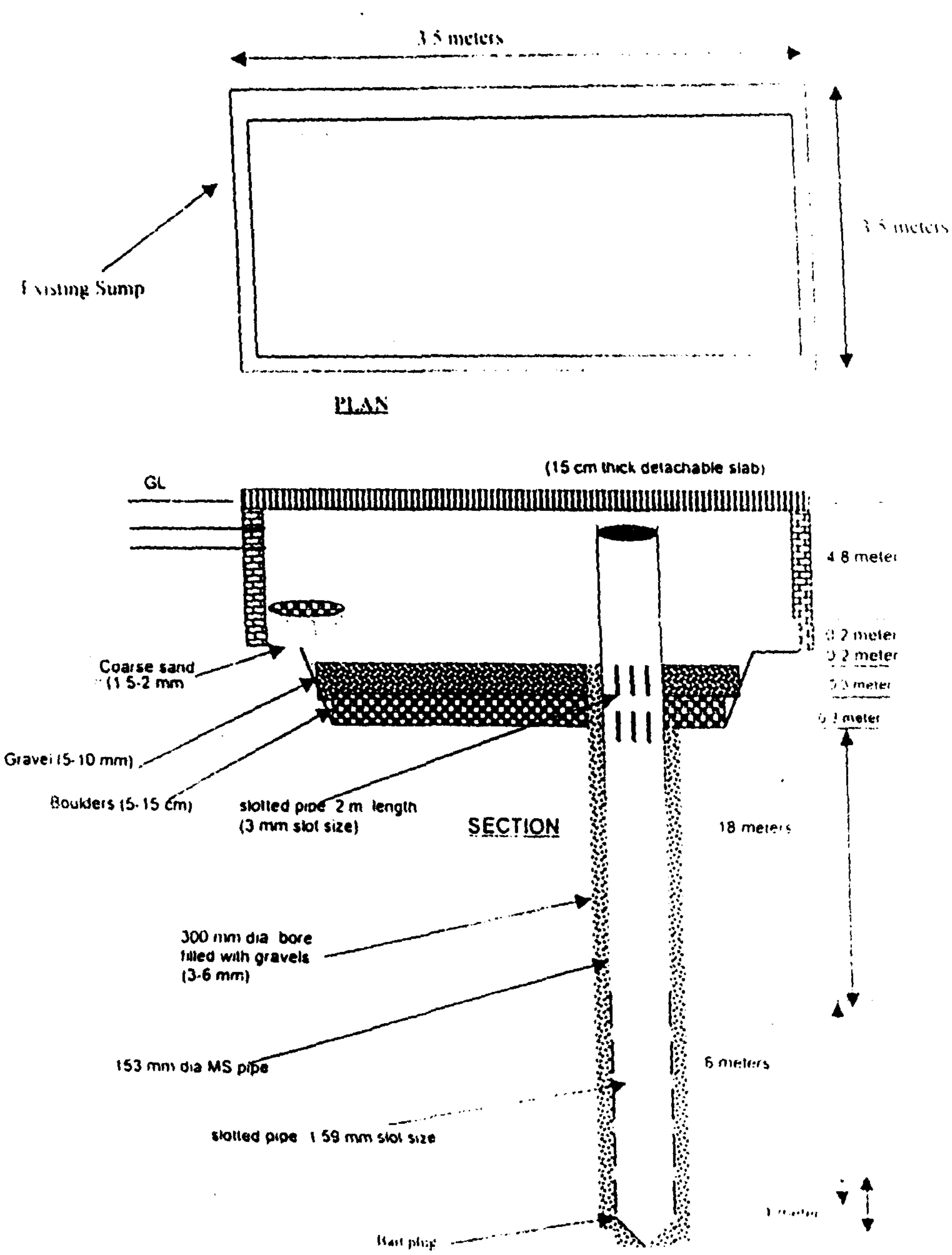


Figure-8.

Recharge Structure - S1 to S4 (Hotel Grand Hyatt)



4.4.8 Check Dams: This is a spreading technique of rainwater harvesting implemented in JNU & IIT area of Delhi. The recharge through four check dams has been 76000 um with a rise in water level from 1 to 13.7 m. Check dams are constructed across small streams having gentle slope. The site selected should have sufficient thickness of permeable bed or weathered formation to facilitate recharge of stored water within short span of time. To harness the maximum runoff in the stream, series of such check dams can be constructed to have recharge on regional scale.

4.4.9 Percolation Tanks: It is also a spreading technique of rainwater harvesting and is implemented at Sultan Ghari. Percolation tank is an artificially created surface water body, submerging in its reservoir a highly permeable land so that surface runoff is made to percolate and recharge the groundwater storage. The recharged area down stream should have sufficient number of wells and cultivable land to benefit from the augmented groundwater. The size of percolation tank should be governed by percolation capacity of strata in the tank bed. Normally percolation tanks are designed for storage capacity of 0.1 to 0.5 MCM. It is necessary to design the tank to provide a ponded water column generally between 3&4.5 m.

4.4.10 Injection Well: Recharge through 2 injection wells in IIT Delhi has been 830 cum with a rise in water level from 0.29 to 0.87 m and benefited area of 1 hectare (Fig. 9).

4.4.11 Recharge Shaft: Recharge shafts and recharge shafts with borewells are most efficient recharge structures where water levels are deep and there is a thick clay layer between the ground level and aquifer system. Recharge Shafts can be constructed in the areas where water level is deep enough i.e. about 8 to 10 m and aquifer is also available at that depth. If water levels are deep, a bore well may be constructed to increase the efficiency of the recharge shaft. In places where storm water drain inlet is deep, recharge shafts can be recommended. Recharge shafts with bore wells are recommended to recharge the runoff generated from roads and flyovers also. In President's Estate runoff generated from the rainfall from a catchment area of 1.3 sq. km. and swimming pool water is being recharged to groundwater through two dugwells, one recharge well and one recharge shaft and two trenches with recharge wells. Rise in water level is of about 4 m in monsoon season of 2003-2004.

Figure-9.

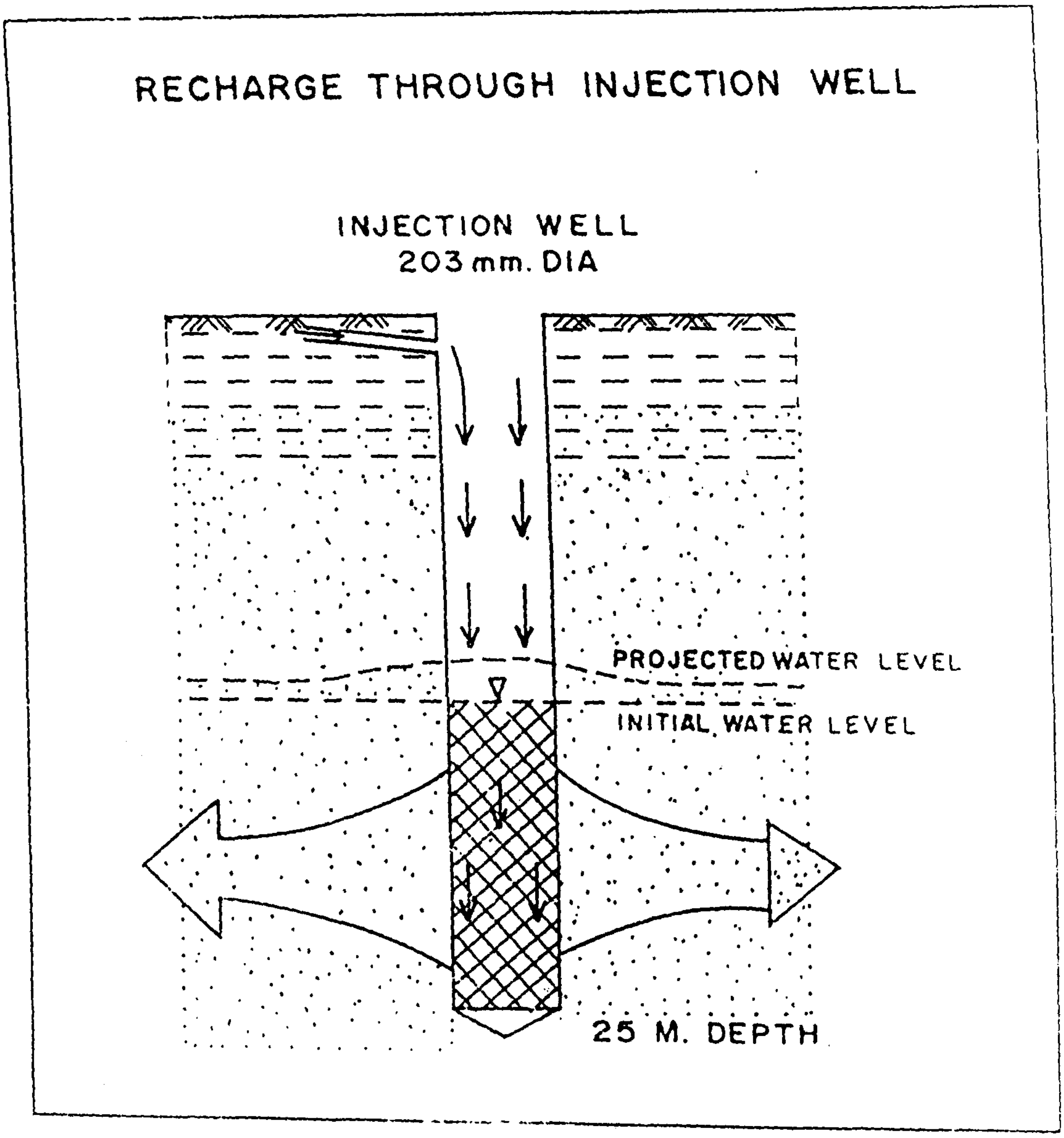

RECHARGE THROUGH INJECTION WELL
INJECTION WELL
203 mm. DIA
PROJECTED WATER LEVEL
INITIAL WATER LEVEL
25 M. DEPTH

Table-2. AVAILABILITY OF RAIN WATER THROUGH ROOF TOP RAIN WATER HARVESTING

Rainfall (mm)	100	200	300	400	500	600	800	1000	1200	1400	1600	1800	2000
Roof top area (sqm)	Harvested Water from Roof top (cum)												
20	1.6	3.2	4.8	6.4	8	9.6	12.8	16	19.2	22.4	25.6	28.8	32
30	2.4	4.8	7.2	9.6	12	14.4	19.2	24	28.8	33.6	38.4	43.2	48
40	3.2	6.4	9.6	12.8	16	19.2	25.6	32	38.4	44.8	51.2	57.6	64
50	4	8	12	16	20	24	32	40	48	56	64	72	80
60	4.8	9.6	14.4	19.2	24	28.8	38.4	48	57.6	67.2	76.8	86.4	96
70	5.6	11.2	16.8	22.4	28	33.6	44.8	56	67.2	78.4	89.6	100.8	112
80	6.4	12.8	19.2	25.6	32	38.4	51.2	64	76.8	89.6	102.4	115.2	128
90	7.2	14.4	21.6	28.8	36	43.2	57.6	72	86.4	100.8	115.2	129.6	144
100	8	16	24	32	40	48	64	80	96	112	128	144	160
150	12	24	36	48	60	72	96	120	144	168	192	216	240
200	16	32	48	64	80	96	128	160	192	224	256	288	320
250	20	40	60	80	100	120	160	200	240	280	320	360	[illegible]
300	24	48	72	96	120	144	192	240	288	336	384	432	[illegible]
400	32	64	96	128	160	192	256	320	384	448	512	576	
500	40	80	120	160	200	240	320	400	480	560	640	720	
1000	80	160	240	320	400	480	640	800	960	1120	1280	1440	[illegible]
2000	160	320	480	640	800	960	1280	1600	1920	2240	2560	2880	[illegible]
3000	240	480	720	960	1200	1440	1920	2400	2880	3360	3840	4320	[illegible]

Chapter 5

Hydrochemistry

HYDROCHEMISTRY

Water is one of our basic natural resources and is the only substance on the earth that appears in three distinct forms of matter within the normal range of the climatic condition. Water is an universal solvent and is major constituents of all living organisms.

Water from surface and underground sources provides sustenance to plants and animals, constituents the habitat for aquatic organisms, and meets important agriculture and industrial needs. Suitability of water for various purposes is based on chemical and biological characteristics of water. Water is the most vital resource for all kinds of life on this plant which adversely effected both qualitatively and quantitatively by all kinds of human activities on land in air or in water.

6.1 Materials and methods:

Collection of water samples and sampling techniques:

The objective of sampling is to collect a portion of material small enough in volume to be transported conveniently and handled in the laboratory while still accurately representing the material being sampled. The samples are collected in a clean and sterilized bottles. The bottle can be sterilized by washing them with concentration HNO_3 or sulphuric acid, which should be completely removed during washing with distilled water.

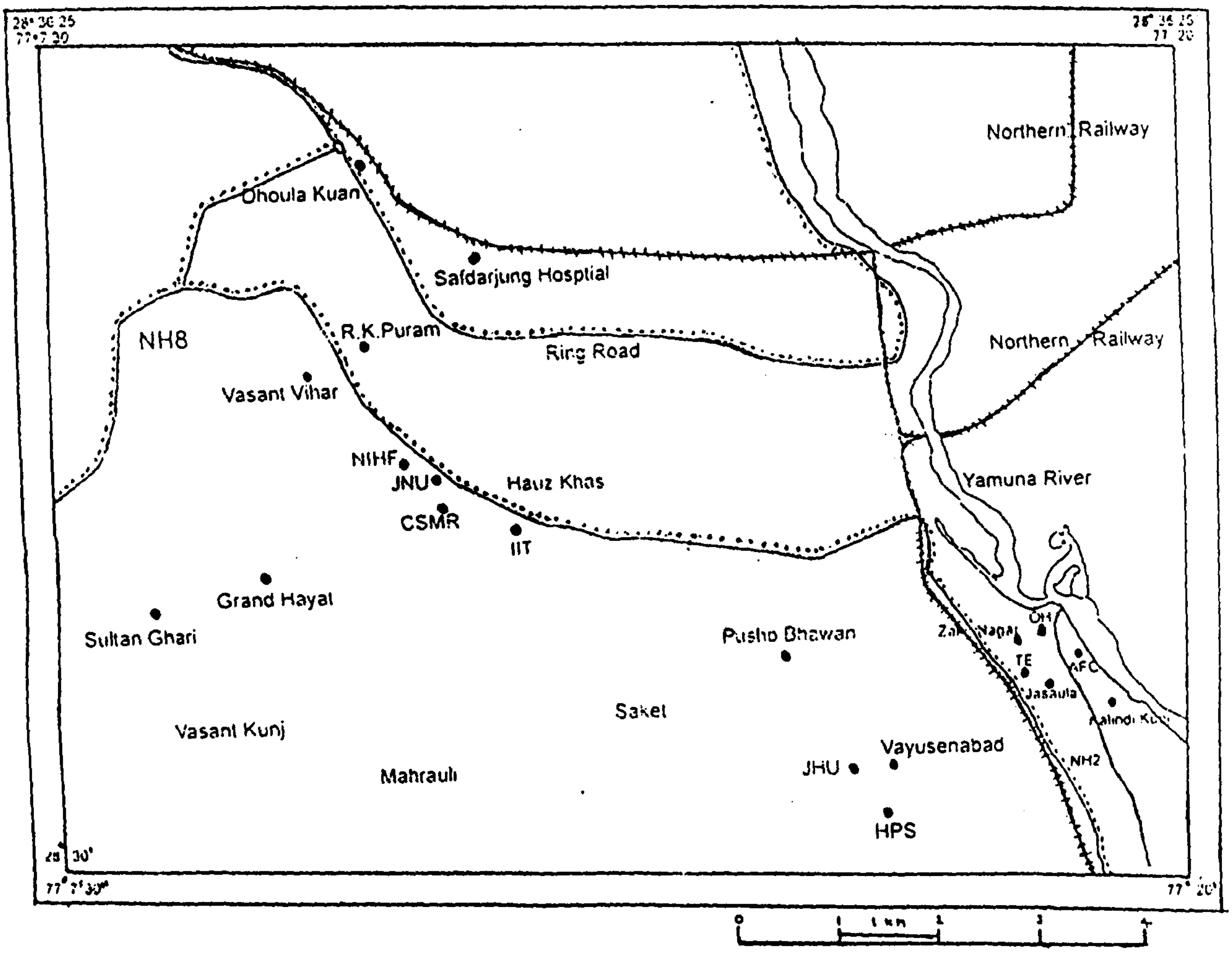


Figure-10. Sampling location map of the study area.

Sample labels are used to prevent sample mis-identification. The sample labels includes the information like sample number, name of the collector, date and time and place of collection.

In the study area the samples are collected from tubewell as well as hand pump.

Sampling is one of the most important step in collection of representative water samples for the water quality studies of surface and sub-surface water bodies. In order to study the chemical character of water, 20 samples were collected during May 2004 from different locations in the study area.

Precautions:

There are various factors such as presence of suspended matter, the method chosen for its removal and the physical and chemical changes brought by storage or aeration, which effect the analytical result. So to avoid the errors in the result, following precautions should be made before collecting the samples:

1. Samples should be collected from wells only after the well has been pumped sufficiently to ensure that the sample represents the groundwater sources.

2. When samples are collected from river or stream, it should be collected from 50-60 cm below the surface in order to avoid surface impurities.

3. Before collecting the sample from hand pump, sufficient water should be pumped.

4. Excessive turbulence area should be avoided because of potential loss of volatile constituents and a potential presence of toxic vapour.

Special precautions are necessary for samples containing organic compounds and trace metals. Because many constituents may be present at concentrations of microgram per litre, they may be totally or partially lost if proper sampling and procedures are not followed.

6.2 Preservation of water samples:

Complete preservation of water samples is practically impossible. Regardless of the nature of the samples, complete stability for every constituents can never be achieved. Sample preservation techniques only retard chemicals and biological changes that continue after sample collection.

To minimize the potential for volatization or biodegradation between sampling and analysis, the sample should kept as cool as possible without freezing. If the immediate analysis is not possible, storage at 4°C is recommended for most samples.

Preservation methods are limited to pH control, chemical addition, and the use of amber and opaque bottles refrigeration, filtration and freezing.

Methods of preservation are limited and are used to:

(1) Retard hydrolysis of chemical compounds,

(2) Retard biological action,

(3) Reduce volatility of constituents.

6.3 Techniques used for analysis of water samples:

Almost all major ions excluding sodium and potassium have been analysed by volumetric method. Sodium and potassium were analysed with the help of flame photometer.

Atomic absorption spectrophotometric method and portable digital voltametric methods are used to determine the quantity of trace elements in water samples.

Electrical conductivity, pH and TDS are analysed with the help of water analysis kit.

Volumetric method:

Major ions such as hardness, calcium, magnesium, chloride, carbonate and bicarbonate, are determined by volumetric method.

Volumetric methods can be classified into four types involving (1) acid-base titration (2) complexometric technique (3) redox reduction (4) precipitation method.

The precipitation titration has wide ranging application in the analysis water samples. The hardness of water can be determined by complexometric titration. The analysis of DO, BOD and COD can be done by redox titration which is the most reliable.

Flame Photometer:

The principle of flame photometry rests on the fact that salts of metals when introduced under carefully controlled condition into a suitable flame are evaporized and exited to emit radiations that are characteristics for each elements. In this method solution of sample is atomized and sprayed into a burner. The intensity of the light emitted by a particular spectral line is measured with the help of photoelectric cell and galvanometer. Sodium and Potassium are determined by this method.

Spectrophotometer:

Photometry refers to the measurement of the light – transmitting power of a solution in order to determine the concentration of light absorbing substances present within Photometry can be applied to measure the transmission of energy in the ultraviolet, infrared, and visible regions of the radiant energy spectrum.

In spectrophotometer, monochromate light is passed through an absorbing column of an often coloured solution of a fixed depth and directed upon photosensitive device which converts the radiant energy into electrical energy. The current produced under these conditions is measured by means of a sensitive voltmeter.

Absorption measured in photometer involves not only the absorbance of the solute in the solution but also all the molecules of the liquid through which the light passes. The greater the number of molecules or ions of absorbing substance present, the greater is the absorption of light. In other words, the more the colour, the greater is the deflection of the voltmeter. Thus the concentration of absorbing component present in a solution may be accurately measured by spectrophotometer.

Portable digital voltameter 2000:

The portable digital voltameter (PDV) is an analytical instrument capable of low level analysis of many metals in the laboratory or field. The technique of anodic stripping voltametry is infact, a form of electroplating on small scale. Metals are first plated onto an electrode from a liquid and then during the subsequent stripping stage, the deposited metals are re-oxidized or stripped back into solution, each metal at its own characteristics potential. The small amount of current generated as each metal oxidizes is measured and correlated with the concentration of metal in the original solution.

With the help of this instrument Cd, Pb and Cu can be detected simultaneously and their concentrations are recorded in a single run. These elements and other such as zinc, Thallium, Antimony, Tin and Bismuth are deposited onto, and stripped from a mercury film plated onto a glassy carbon electrode. Concentration down to one part per billion in the cell solution can be detected. For those elements such as mercury (Hg), silver (Ag), and gold (Au) which do not allow a mercury film to be used on the electrode surface, a lower detection limit of 50 ppb in the cell solution is appropriate.

6.4 DETERMINATION OF pH AND E.C. WITH WATER ANALYSIS KIT:

6.4.1 Hydrogen ion concentration (pH):

Measurement of pH is one of the most important and frequently used test in water chemistry. Measurement of pH with this instrument is accomplished by determining the potential developed by electrode. It is a measure of acidity or alkalinity of a substance.

Procedure:

The pH electrode is connected to the input socket at the front of the instrument. Electrode is cleaned with distilled water and dipped in the

4.00 pH buffer solution which is supplied with the instrument. After measuring the temperature of the buffer solution, temperature knob is fixed at the temperature of the solution. After pushing the pH switch, with the help of CAL knob, display to 4.00 pH is adjusted. Now the instrument is calibrated.

The electrode is washed, dried and dipped in the solution whose pH is to be measured. After keeping the temperature at the proper position, reading of pH can be noted.

6.4.2 Electrical Conductivity (E.C.):

Conductivity is a measure of the ability of an aqueous solution to carry an electric current. This ability depends on the presence of ions, their total concentration, mobility, and valence and on the temperature of measurements.

Procedure:

The conductivity cell is connected to the input socket for conductivity. The cell is dipped in 0.1 HCl solution whose specific conductivity is known after pushing the conductivity switch, conductivity range is adjusted at 200 m moho position. After measuring the temperature of the solution reading is adjusted with the help of CAL knob as per the chart supplied with the instrument. Now instrument is calibrated.

Conductivity cell is washed with distilled water and dipped in the unknown solution. It will give direct reading after selecting the proper range.

Chemical characteristics:

The hydrochemical data of water samples collected from groundwater bodies are given in Table 6, 7, 8 and 9. The chemical behaviour of different major ions is shown in Figure 13, 14 and 15.

(i) In the EC ranges upto 4500 micro-seimens/cm, there is an increase in bicarbonate ions with increase in EC. After these ranges bicarbonate ions decrease with increase in EC which can be attributed to precipitation of carbonate bearing minerals.

(ii) Calcium ions in comparison to magnesium ions present to a higher extent. In general both the ions increase with increase in salinity.

(iii) In low E.C. ranges the concentration of total hardness is predominant. With the increase of salinity, there is increase in average value of total hardness.

(iv) There is a rapid increase in the average value of chloride ions with increase in E.C. Chloride ions are the major contribution to the salinity.

(v) Sodium ions are the predominant cation that may be due to leaching from sodium bearing minerals or due to clays as a result of ion-exchange reaction. Potassium ions are present in low concentrations.

6.5 Water quality parameters in the study area:

The quality of water largely depends on a number of individual hydrological, physical, chemical and biological parameters are of special importance and deserve frequent attention and observation, others give a rough picture of water quality status. The graphical representation of major ions and trace elements are shown is Figs. 13, 14, 15, 23, 24 and 25.

During the present study the following constituents of water analysed shown in Table 3. The concentrations of major ions and trace elements are given in Tables 6, 7, 8 and 9.

Table–3

Physical parameters	**Chemical parameters**	**Major cations**	**Major anions**	**Trace elements**
E.C.	PH T.D.S. Hardness	Calcium Magnesium Sodium Potassium	Bicarbonate Carbonate Chloride Sulphate	Zinc Lead Copper Iron Manganese Chromium Nickel Cobalt

6.6 DISTRIBUTION OF MAJOR IONS:

Hydrogen ion concentration (pH):

The pH value of the water represents the concentration of hydrogen ion and is a measure of acidity and alkalinity of water. pH does not measure total acidity or alkalinity.

In fact the normal acidity or alkalinity depends upon excess hydrogen ions are more than hydroxyl ions over the other. If free hydrogen ions are more than hydroxyl ions the water shall be acidic.

In other words hydrogen ion concentration in water is the logarithmic reciprocal of their weights measured in grams per litre of water.

The pH value of acidic water varies from 0-7 and that of alkaline water between 7-14, while neutral water has a pH value of 7.0. Generally the fresh water has a pH value of 6-8.

The pH value of water in the study area are in the range of 7.1 – 8.8 averaging 8.2

The samples collected from groundwater bodies by the source of tubewell as well as handpump. All the samples collected from study area are alkaline in nature.

The areas where higher value of pH is observed are Jamia Hamdard University (pH 8.6), Seva Bhavan in R.K. Puram (pH 8.4), Centre for Soil and material Research (CSMR) (pH 8.4), National Institute of Health and Family Welfare (pH 8.5), Abul Fazal Enclave (pH 8.7) and Kalindi Kunj (pH 8.7) during pre-monsoon period.

The pH values are within the permissible limits for domestic use almost all the locations in the study area. The high values of pH 9.1 has been observed at Kalindi Kunj during post-monsoon period.

Electrical conductivity:

Electrical conductivity is the measure of capacity of a substance or solution to conduct electric current. Electrical conductivity is reciprocal of the resistance. Electrical conductivity of water is having direct relationship with the concentration of ionized materials present in water. Electrical conductivity gives an idea about extent of mineralisations and is indicative of the salinity of groundwater.

The value of electrical conductivity in the study area ranges from 300 µsiemens/cm to 3600 µsiemens/cm with an average of 920 µsiemens/cm at 25°C in premonsoon period. The value of electrical conductivity 600 µsiemens/cm to 3500 µsiemens/cm with an average value of 1050 µsiemens/cm at 25°C in postmonsoon period. Almost at all locations in study area electrical conductivity increase in the postmonsoon period. The samples taken from Taj Enclave, Abul Fazal

Enclave, Okhla and Kalindi Kunj exhibit a higher values of electrical conductivity.

The water sample from Taj Enclave is highly saline in comparison to other samples with E.C. value 3500 µsiemens/cm. The lowest value of E.C. during the pre-monsoon period has been observed 300 µsiemens/cm, while a high value was observed is 600 µsiemens/cm from Vasant Kunj area during the post-monsoon period.

Total Dissolved Solid (TDS):

Total quantity of chemical constituents present in water is called total dissolved solid. TDS is an important criteria which measures the suitability of water for irrigation. In natural water total dissolved solids are composed mainly of carbonates, bicarbonates, chlorides, sulphates, phosphates and nitrates of calcium, magnesium, sodium, potassium, iron and manganese etc. Concentration dissolved solid is an important parameter in drinking water and other water quality standards. The permissible limit of total dissolved solid prescribed by I.C.M.R. (1975) is between 500-1500 ppm.

The values of total dissolved solids in the study area ranges from 192 ppm to 2176 ppm with an average value of 556.8 ppm in premonsoon period. The values of TDS ranges from 384 ppm to 2240 ppm within average value of 665.6 ppm in post-monsoon period. The highest concentration of TDS recorded from Abul Fazal Enclave, Taj Enclave and Kalindi Kunj. Water with high concentration of TDS is generally palatable and may have laxative effect on people.

Total Hardness:

Hardness of water is related to its capacity to produce leather from soap. The hardness is caused by the presence of carbonates of calcium and magnesium, and chloride and sulphate of calcium and magnesium. However, other cations such as strontium, iron and manganese also contribute to the hardness. Hardness is called temporary if it is caused by bicarbonate and carbonate salts of cations, since it can be removed by simply boiling water. Permanent hardness is caused mainly by sulphates and chlorides of the metals.

The hardness in water is derived from the solution of carbon dioxide, released by bacterial action in the soil, in percolating rainwater. Water has been classified as hard or soft according to their action on the soap. The less amount of soap is consumed to produce leather, the softer the water. On the basis of hardness, water is classified as follows:

S.No.	Hardness (ppm)	Water class
1.	Less than 50	Soft
2.	50 to 100	Moderately soft
3.	100 to 150	Slightly hard
4.	150 to 250	Moderately hard
5.	250 to 350	Hard
6.	More than 350	Excessively hard

The hardness in the study area varies from 100 ppm to 620 ppm with an average value of 210.4 ppm during premonsoon period. The hardness ranges from 172 ppm to 728 ppm with an average value of 307.5 ppm in postmonsoon period. For drinking water I.S.I. (1983) has prescribed total hardness of 300 ppm as desirable limit and 600 ppm as permissible limit. In general the water of the area is moderately hard. In most of the sample, hardness below the desirable limit. The sample collected from Kalindi Kunj exhibits maximum concentration of hardness (620 ppm in premonsoon and 728 ppm in postmonsoon) which exceeds the permissible limit for drinking purpose.

MAJOR CATIONS:

(1) Calcium: Calcium is one of the most important cations present in groundwater. The main source of calcium in groundwater are rainwater, leaching from fertilizers, soil amendment, weathering of calcium silicate minerals and use of surface water for irrigation. The dissolved CO_2 generally controls the calcium ion. Disposal of sewage and industrial waters are also important sources of calcium. The maximum desirable limit of calcium in drinking water is 75 ppm (WHO, 1984, ISI: 1983). Calcium content in groundwater of the stdy area range from 24.04 ppm to 52.16 ppm with an average value of 35.83 ppm in premonsoon period and range from 28.85 ppm to 88.17 ppm with an average of 48.06 ppm in postmonsoon period. According to USPH (United State Public Health, 1962) the maximum permissible limit for calcium is 100 ppm. Most samples collected from study area are below desirable limit. Calcium is an essential constituents for human body which requires 0.7 to 2.0 gm/day. In human body it is essential for muscular and nervous system. Low levels of calcium may have adverse affects on human health. Higher content is also harmful resulting in the formation of kidney and bladder stones and irritation in urinary massages.

(2) **Magnesium (Mg):** Magnesium is one of the most important contributors to the hardness of water. The concentration of magnesium in groundwater were less than calcium possibly due to lesser occurrence of magnesium mineral. The chief sources of magnesium in groundwater are rainwater, weathering of magnesium silicate minerals present in the soils and use of surface water for irrigation.

The permissible limit of magnesium for drinking purposes varies from 30 to 150 ppm (WHO, 1984). Indian Council of Medical Research (I.C.M.R., 1975) has prescribed 50 ppm as maximum desirable limit and 100 ppm as maximum permissible limit.

The magnesium concentration in the area ranges from 1.94 ppm to 140.62 ppm in premonsoon period and ranges from 19.49 ppm to 159.83 ppm in postmonsoon period. In the study area the magnesium concentration is below the desirable limit in most of the water sample, other sample shows the concentration within the maximum permissible limit. The highest concentration has been observed at Kalindi Kunj (159.83 ppm). In the most part of the study area, the magnesium contents are below 60 ppm. Magnesium is an essential nutrient for human body with an average adult requirement of 200 to 300 mg/day. Magnesium deficiency is associated with structural functional changes and may cause severe diarrhoea, chronic renal failure and protein-caloric malnutrition (WHO, 1973).

(3) **Sodium (Na):** Sodium is present in nearly all natural water and its concentration in groundwater depends on hydrogeological conditions industrial activities and weathering of rock minerals present in soil. The most important water quality aspect of sodium is the possibility of changing the permeability of soil.

The guideline value of sodium is given as 200 ppm which is based on taste consideration (WHO, 1984). In the study area sodium content varies from 25.40 ppm to 379.06 ppm in premonsoon period and from 20.00 ppm to 45.00 in postmonsoon period. The highest concentration of sodium were recorded frm Taj Enclave (379.06 ppm). Almost 50% of samples exhibit the sodium concentration more than 200 mg/l and in about 25% samples sodium concentration less than 150 mg/l. Higher values have been observed at Taj Enclave and Kalindi Kunj. Low values were observed at Vasant Kunj, CSMR. Though sodium is an essential element for human body, its higher content in drinking water may be harmful to a person softening from cardio and renal diseases pertaining to circulatory system.

Sodium Percent:

Sodium content is usually expressed in terms of percent sodium which is also known as sodium percentage and soluble sodium percentage. Sodium percentage is calculated by the following expression:

$$\text{Sodium percentage} = \frac{(Na + K)}{Ca + Mg + Na + K} \times 100$$

where all ionic concentrations are expressed in milli-equivalent per litre. The sodium percentage values in the study area ranges from 37.33 ppm to 83.57 ppm with an average of 66.00 ppm in premonsoon and ranges from 15.09 ppm to 100 ppm with an average of 55.87 ppm in postmonsoon period. The maximum sodium percent values were calculated at Taj Enclave as well as Kalindi Kunj.

The vales of percent sodium against electrical conductivity are compared and plotted on Wilcox diagram (Fig. 16). The diagram reveals that there is variation in groundwater quality of the area. About 47 percent of the water sample fall in excellent to good; 17 percent in good to permissible and 35 percent fall in permissible doubtful class.

Sodium Adsorption Ratio (SAR):

Relative proportion of sodium to calcium and magnesium is expressed as Sodium Adsorption Ratio (SAR)

$$SAR = \frac{Na}{\sqrt{(Ca + Mg)/2}}$$

Where all ionic concentrations are expressed in milliequivalent per litre. Sodium adsorption ratio was recommended by the salinity laboratory of the U.S. Department of Agriculture (1962). Sodium adsorption ratio is usually calculated, because of the direct relation of sodium to adsorption by soil.

The TDS, expressed in terms of EC and sodium adsorption ratio from the basis of classification of water for irrigation purposes (Fig. 17). The salinity hazards increases resulting in the concentration of salts in the soil that may require periodical leaching. Excessive sodium content in water renders it unsuitable to soils containing exchangeable calcium and magnesium. In Fig. (8) water samples show medium to high salinity hazard and low alkali hazard.

(4) Potassium (K):

Potassium is less common cation as compared to sodium in groundwater which may be as a result of reactions with clay minerals. The main sources of potassium in groundwater of the area are use of potash fertilizers, weathering of potash silicate minerals and rainwater.

In study area potassium varies from 1.00 ppm to 800 ppm in premonsoon and ranges from 2.00 ppm to 20.00 ppm in postmonsoon period. The highest value has been recorded from Okhla head (79.00 ppm). The lower value from Vasanj Kunj (1.00 ppm). As such potassium is not very much significant from health point of view but large quantities may be laxative.

Major Anions: Cl^-, HCO^-_3, CO^-_3, SO_4^-

(1) Chloride (Cl^-):

The major sources of chloride in groundwater are sewage, industrial effluents. Chloride content in rain water is usually less than 10 ppm. Locally, the chloride content of rain water may be high in coastal areas and in desert tracts. Chloride bearing minerals such as sodalite and chloroapatite which are very minor constituents of igneous and metamorphic rocks. I.S.I. (1983) has prescribed highest desirable limit of 250 ppm and maximum permissible limit of 1000 ppm in drinking water supply. Chloride ions are the major contribution to the salinity of water. W.H.O. (1984) has suggested 200 ppm of chloride as desirable limit and 600 ppm as maximum permissible limit in drinking water.

In the study area concentration of chloride ranged from 40.03 ppm to 308.63 ppm in premonsoon and ranges from 22.72 ppm to 340.80 ppm in postmonsoon period. The high concentration of chloride was recorded at Taj Enclave, Okhla head, Pushp Vihar, Safdarjung Hospital and Kalindi Kunj. The sample collected from Vasant Kunj shows a low concentration of chloride (42.6 ppm in premonsoon).

(2) **Carbonate (CO_2):** The major source of carbonate in natural fresh water are limestone and dolomite. Carbonate concentration in the study area are ranges from 10 ppm to 40 ppm in premonsoon and ranged from 20-60 ppm in postmonsoon period. The highest concentration of carbonate was exhibit by the Jamia Hamdard University in premonsoon.

(3) **Bicarbonate (HCO_3):**

Bicarbonate is the major anion found in groundwater of the area under investigation. Main sources of bicarbonate in groundwater include carbon dioxide in atmosphere, carbon dioxide in the soil, leaching from carbonaceous rocks and carbon dioxide released due to bacterial oxidation of organic matter.

$$CO_2 + H_2O = H^+ + HCO^-_3$$

$$CaCO_3 + CO_2 + H_2O = Ca^{++} + 2HCO^-_3$$

The range of bicarbonate concentration in the study area is 30 ppm to 145 ppm with an average of 54.00 in premonsoon and ranges from 20 ppm to 150 ppm with an average of 46.00 ppm. The maximum concentration of bicarbonate observed at Kalindi Kunj (150.00 ppm) and Okhla head (100.00 ppm) during post-monsoon period.

(4) Sulphate (SO_4):

Sulphate is predominant anion present in wide range of concentration in natural water. The chief source of sulphate in groundwater are; sulphate minerals in sedimentary rocks, oxidation of sulphides from igneous rocks and volcanic emanations, addition of soil amendments such as gypsum, pyrite, fertilizers and rainwater.

Analytical results Table 6 and 7 shows that the concentration of sulphate in groundwater ranged from 52.62 ppm to 493.62 ppm in premonsoon and ranged from 68.309 ppm to 592.88 ppm in postmonsoon period. The highest concentration recorded at Taj Enclave (592.88 ppm), Jamia Nagar (457.58 ppm) and Hamdard Public School (168.71 ppm).

Both I.C.M.R. (1975) and W.H.O. (1984) have prescribed highest desirable limit of 200 ppm for sulphate in drinking water. Sulphate concentration in groundwater were within the permissible limit except at Taj Enclave where the concentration of the sulphates has been recorded 493.62 ppm.

Sulphates at higher concentration can have laxative effect (W.H.O., 1984). Sulphates ions when associated with high concentrations of magnesium and sodium ions and as laxative and may cause gastric disorders. Sulphate values in drinking water exceeding 500 ppm impart bitter taste and may cause gastrointestinal irritation (Kakar, 1989).

6.7 Hydrochemical facies:

The diagram presented above are useful for visually describing differences in major ion chemistry in groundwater flow system. In order to represent water composition in a convenient manner by identifiable groups, Back (1961, 1966), Morgan and Winner (1962) have developed the concept of hydrochemical facies.

Hydrochemical facies are distinct zones that have cation and anion concentrations describable within the defined composition categories (Allan and Cherry, 1979). According to Back (1961) the term hydrochemical facies is used to described the bodies of groundwater in an aquifer that differ in their chemical composition. The facies are a function of lithology, solution kinetics and flow pattern of the aquifer (Back, 1966).

The percent values of cation and anion have been plotted on trilinear piper diagram (Fig. 18 and 19) as suggested by Morgan and Winner (1962) and Back (1966) in order to designate hydrochemical facies of the study area. The plotting of analytical results shows that sodium or potassium is the dominant facies among the cations. Only four samples fall in no dominant type facies. Rest, one sample fall in the calcium type facies in the premonsoon. Among the anion facies, most samples fall in the chloride type facies. Five samples fall in no dominant type facies. Rest of the samples belong to the sulphate type facies in the premonsoon period. During the postmonsoon, Fig. (19) plotting shows that most of the samples fall in the no dominant type facies. Six samples fall in the calcium or potassium type facies. Rest of samples belong to the magnesium type and calcium type facies among the cation. Among the anion facies, almost 80% samples belong to the sulphate type and chloride type facies. Only four samples in the no dominant type facies.

Gibbs (1970) variation diagram has been used to study the mechanism controlling water chemistry. It is observed that water chemistry of the area reflects the field of rock dominance (Figs. 20 and 21) indicating that major mechanism controlling the water chemistry is the weathering of rocks (during pre-monsoon and post-monsoon).

In the modified piper diagram Figs. 22 and 23 The difference in percentage between alkaline earth (calcium and magnesium) and alkali metals (sodium and potassium) in terms of percentage reacting value is plotted on x-axis while difference in percentage between weak acidic anions (CO_3 and HCO_3) and strong acidic anions (Cl and SO_4) in terms percentage reacting value is plotted on y-axis. It is observed from Figs. 22 and 23. That majority of groundwater samples fall in the field 6 and 7. Indicating alkali metals exceeding alkaline earths and strong acid exceeding weak acid. Such water can be classified into high salinity group and may cause salinity problem both in irrigation and domestic uses. The field 7 represents Ca-Mg-Cl type water. The second field 5, shows alkali metal exceeding alkaline earths and weak acid exceeding strong acids. Such water imparts residual sodium carbonate hazards in irrigation use and would cause foaming problem in boiler, if used as boiler feed water. This field plotting represents Na-HCO_3 type water. A few sample fall in the field 5 indicating temporary and permanent hardness respectively for groundwater.

6.8. TRACE ELEMENTS AND ITS EFFECT ON WATER QUALITY:

Heavy metals having density more than five times higher than water are usually found in trace amount in natural water therefore, they are referred as trace elements. Natural levels of trace elements are inherited primarily from the rocks by weathering processes. The natural levels of these elements are usually harmless to the organisms but the pollution due to mining activities, industrial effluents, agriculture chemicals and fossil fuels have considerable increased their global levels. Anthropogenic resources of several metals like cadmium, zinc, lead, and mercury have been reported to exceed the natural flukes which have resulted in continuous buildup of these metals in different components of the environment (Goel, 1997). The increase in concentration of metals in a localized area reaching some times to significant higher levels and become deterious to biological pollution and human beings. Metal ions and their complexes exhibit a wide range of toxicity to the organisms that ranges from sublethal to lethal depending upon the time of exposure and the prevailing conditions in the ambient water.

Metals such as Zn, Pb, Cu, Fe, Mn, Cr, Ni and Cobalt (Tables 8 and 9). Dispersion of these elements in groundwater of the area, their sources and various health hazards are discussed individually as below.

(1) Zinc (Zn):

Zinc is an essential and beneficial element for human bodies. Pollution from industrial and agricultural sources to a great extent are responsible for high concentration of zinc in water. Natural sources of zinc are sulphide and carbonate ore. Zinc in groundwater to a small extent may be derived from natural sources. The sources of atmospheric zinc pollution include smelter, iron and steel manufacturing processes, combustion of coal and oil etc. But concentration above 5 ppm cause bitter taste and opalescence in alkaline waters.

In drinking water, the concentration of zinc ranges from 0.06 ppm to 7.0 ppm prescribed by ISI (1983) and WHO (1984). The value from 0.0302 ppm to 0.8432 ppm with an average value of 0.2175 ppm in postmonsoon period. The concentration of zinc in the study area is below the highest desirable limit (5-15 ppm ISI, 1983). A high concentration of zinc 0.8432 ppm has been seen CSMR and 0.6675 ppm at Taj Enclave.

Zinc plays an important role in enzymes and many enzymatic functions, protein synthesis and carbohydrate metabolism (Taylor and Demayo, 1980). It is responsible for cell division and growth zinc deficiency in human body may results in infantilism, impaired wound healing and several other diseases.

(2) Lead (Pb):

Main sources of lead connected with pollution are effluents of industries such as paints, storage batteries, printing and dyeing etc. impurities in fertilizers and insecticides. Lead is a very serious body poison. Lead salts are used as anti-knocking compounds in fuel for gasoline engine which is a major source of lead pollution in atmospheric environment.

The high concentration of lead have adverse effects on the central nervous system, blood cells, kidney and may cause brain damage. As a result ingestion of lead, there may be loss of appetite, fatigue, irritation, headache and vomiting (Stephen, 1972). In the study area the concentration of lead ranges from 0.0167 ppm to 0.2916 ppm with an average of 0.1180 ppm during premonsoon period. The water samples shows the ranges from 0.0291 ppm to 0.3198 ppm with an average of

0.1241 ppm in postmonsoon period. The higher concentration of lead has been recorded at Safdarjung Hospital (0.1733 ppm), Abul Fazal Enclave (0.2116 ppm) and Vasant Kunj (0.2916 ppm). As per the W.H.O. (1984) standards the maximum permissible limit is 0.1 ppm.

(3) Copper (Cu):

Copper is an essential trace element for human body. Copper in natural waters results in higher concentration due to pollution. It is used with sulphate as a pesticide and also separately as an algaecide. The daily requirement of copper for an human an adults is 2 ppm (Mc Neely et al., 1979). The sources of copper that enhance the concentration in water include mining waste, paints, pumping equipments, pesticides and industrial effluents from electroplating units.

The concentration of copper in water of the study area ranges from 0.0085 ppm to 0.0579 in premonsoon period and from 0.0061 ppm to 0.3198 ppm with an average of 0.0389 ppm in postmonsoon. The copper concentration in most of the water samples are lower than the prescribed permissible limit as prescribed by WHO and ISI (i.e. 0.05 – 1.5 ppm, ISI, 1983). The high concentration of copper has been observed as Safdarjung Hospital (0.3198 ppm). Copper is involved in hemoglobin synthesis, connective tissue development and normal function of central nervous system. Copper deficiency is linked with anaemia, diarrhoea, demineralization of bone etc. Wilson disease has been associated with abnormal copper metabolism.

(4) Iron (Fe):

Iron is a common constituents of soil and rocks and is derived from weathering of ferruginous minerals of igneous rocks and sulphide ores of sedimentary and metamorphic rocks.

The concentration of iron in the study area ranges from 0.1238 ppm to 1.6777 ppm with an average value of 0.4392 ppm in premonsoon period and 0.1499 to 3.4777 ppm with an average value of 0.7987 ppm in postmonsoon water samples. The maximum concentration of iron (Fe, 3.477 ppm) has been detected from the water sample collected from C.S.M.R. In most of water samples the values are less than 0.5 ppm.

The high concentration of iron have been observed at Safdarjung hospital (0.5026 ppm), Vasant Kunj (1.6777 ppm), Okhla head (0.4508 ppm) and Centre for Soil and Material Research (C.S.M.R.) 1.0333 ppm. The highest desirable limit of iron 0.3 ppm and maximum permissible limit is 1.0 ppm. Iron is essential element for man. It is controlled in the human body mostly in the small intestine where both absorption and excretion takes place when iron is present in high concentration, it imparts bitter taste and inky flavour.

(5) Manganese (Mn):

Manganese, like iron, is also a naturally, derived metallic pollutant, and resembles with it in many pollutional aspect. The important natural sources of manganese are soils, sedimentary and metamorphic rocks. Manganese occurs in both the dissolved and suspended forms. It is adsorbed on the clays, organic matter, hydrated iron oxides, silicates etc.

Manganese concentration in groundwater of the study area are ranges from 0.0048 ppm to 1.0461 ppm with an average value of 0.1704 ppm in premonsoon and 0.0078 ppm to 1.7636 ppm with an average value of 0.5100 ppm in postmonsoon period. The high values of manganese has been observed at Safdarjung Hospital (1.7636 ppm)and Jamia Nagar (1.0207 ppm) which exceed the permissible limit of ISI (1983) i.e. 0.1 ppm to 0.5 ppm.

Manganese is an essential element for nutrition of man. Its deficiency may inhibit growth, disrupt the nervous system and interfere with a reproduction functions (Mc Neely et al., 1979). Higher cncentration of manganese is toxic and may cause a disease of central nervous system involving neurological disorder (Mena et al., 1967).

(6) Chromium (Cr):

Chromium is one of the most widely distributed heavy metals in the earth crust. It is found in two oxidation states i.e. Cr^{+3} and Cr^{+6}. Cr^{+3}

gets easily oxidized to Cr^{+6} which is more toxic the trivalent form is not present in waters with a pH greater than 5 due to low solubility of its hydrated oxide (Mc Neely, 1979).

Chromium is used in electroplating, pigments, tanneries, photographic materials, wood preservatives and corrosion inhibitors. Several industries use chromate for making refractory materials and a number of chromium containing materials. The highest desirable limit of chromium is 0.05 ppm as represented by (WHO, 1984 and ISI, 1983). In the study area the concentration of the chromium ranged from 0.0772 ppm with an average value of 0.3448 ppm in premonsoon and 0.255 ppm to 1.062 ppm with an average value of 0.4450 ppm in postmonsoon period. The highest concentration of chromium has been recorded from water sample collected from Safdarjung hospital. In the study area the concentration of chromium exceed the highest desirable limit in most of the groundwater samples.

Toxicity of chromium is greatly dependent upon the hardness of water. Chromium toxicity also varies with temperature, pH, oxidation state (Goel, 1997). Hexavalent chromium (Cr^{+6}) is much more toxic than trivalent chromium (Cr^{+3}) but it has no nutritional value and may be absorbed through the skin and-by the inhalation and corrosion (US Environmental Protection Agency, 1983). Occupational hazards of hexavalent chromium cause skin and respiratory disorders and ulceration of skin.

(7) Nickel (Ni):

Nickel is not commonly found in natural deposits. The solubility of nickel salts in water is quite low. Due to formation of complexes and adsorption on iron and manganese hydroxide during percolation, the concentration of nickel in groundwater are usually low. Effluents of electroplating wastes, steel alloy industries, dyes and textiles nickel cadmium batteries and chemical industries are the possible sources of nickel in groundwater in the study area.

The concentration of nickel ranged from 0.0243 ppm to 0.1434 ppm with an average value of 0.0782 ppm in premonsoon and 0.0621 ppm to 0.1285 ppm with an average of 0.0889 ppm in postmonsoon period. Since WHO and other agencies have not prescribed any limit for nickel in drinking water supplies. It is difficult to critically evaluate the extent of Nickel pollution in the study area. The highest concentration of nickel has been observed at Abul Fazal Enclave (0.1285 ppm). High concentration of Nickel are harmful for human health Nickel salts in aqueous solution cause dermatitis and repeated inhalation of nickel compounds may cause lung cancer (Mc Neely, 1979).

(8) Cobalt:

Cobalt is also trace element of water. In the study area the concentration of cobalt varies from 0.0123 ppm to 0.1533 ppm with an average value of 0.0638 ppm in premonsoon and 0.0529 ppm to 0.1467 ppm with an average value of 0.0899 ppm in postmonsoon period. The highest value cobalt has been observed from groundwater sample collected from Abul Fazal Enclave (0.1467 ppm).

Table-3.

TOXICOLOGICAL EFFECTS OF HEAVY METALS WATER POLLUTANTS ON MAN:-

Metals	Toxicological Effects On Man
1. Lead	: vomitting, anaemia, loss of appetite, damage of brain, liver and kidney, convulsions.
2. Cadmium	: diarrhoea, growth retardation, kidney damage bone deformation, testicular atrophy, anaemia injury of central nervous system, and liver, hypertension.
3. Arsenic	: disturbed peripheral circulation, mental disturbances, liver cirrhosis, hyperkeratosis lung cancer, kidney damage.
4. Copper	: hypertension, uremia, coma, sporadic fever.
5. Zinc	: vomitting, renal damage, cramps.
6. Hexavalent Chromium	: nephritis, gastro-intestinal ulceration; disease in central nervous system, cancer
7. Cobalt	: diarrhoea, low blood pressure, paralysis bone deformation.
8. Mercury	: abdominal pain, headache, diarrhoea, chest pain, hemolysis

Table-4.

PRESERVATION METHOD

Parameter	Preservation	Max. Holding Period
Calcium	None required	7 days
Acidity/alkalinity	refrigeration at 4 ^{0}C	24 hours
BOD	refrigeration at 4 ^{0}C	6 hours
COD	2 ml sulphuric acid/litre	7 days
Colour	refrigeration at 4 ^{0}C	24 hours
Dissolved oxygen	determined on site	-----
Chloride	none required	7 days
Fluoride	none required	7 days
Hardness	none required	7 days
Total Metal	5 ml nitric acid/litre	6 months
pH	determination on site	-----
TDS	none required	7 days
Turbidity	none required	7 days
Sulphate	refrigeration at 4 ^{0}C	7 days
Sulphide	2 ml zinc acetate/litre	7 days
Conductivity	refrigeration at 4 ^{0}C	28 days

Table-5: Range of Chemical Constituents in Groundwater Samples and their comparison with WHO (1984) and ISI (1983) drinking water standards

Constituents	WHO (1984)		ISI (1983)		Concentration Range in study area (ppm)	
	Highest desirable limit (mg/L)	Maximum permissible limit (mg/L)	Highest desirable limit (mg/L)	Maximum permissible limit (mg/L)	Pre-monsoon	Post-monsoon
pH	7 – 8.5	6.5 – 9.2	6.5 – 8.5	6.5 – 9.5	7.1 – 8.7	8.1 – 9.1
Total Hardness	100	500	300	600	100.0 – 6.20	180.0 – 728.0
Calcium	75	200	75	200	24.04 – 52.16	28.85 – 88.17
Magnesium	-	150	30	100	1.95 – 140.62	19.49 – 159.83
Nitrate	45	45	45	45	-	-
Chloride	200	600	250	1000	42.62 – 308.63	22.72 – 340.80
Fluoride	1.0	1.5	1.0	1.5	-	-
Sulphate	200	400	150	400	52.62 – 493.62	68.30 – 592.88
Iron	0.1	1.0	0.3	1.5	0.1238 – 1.6777	0.1499 – 3.4777
Copper	0.05	1.5	0.05	1.5	0.0085 – 0.0521	0.0061 – 0.3198
Manganese	0.05	0.5	0.1	0.5	0.0118 – 1.0461	0.0078 – 1.7636
Zinc	5	1.5	5	1.5	0.0036 – 0.4378	0.0302 – 0.8432
Cadmium	-	0.01	0.01	No relaxation	-	-
Lead	-	0.1	0.1	No relaxation	0.0167 – 0.2916	0.0291 – 0.3124
Chromium	-	-	0.05	No relaxation	0.0724 – 0.8240	0.225 – 1.0624

Table-6: Physico-chemical parameters and hydrochemical data of the groundwater samples (mg/L) (Pre-monsoon May 2004)

Sm. No.	Location	EC µS/cm	pH	TDS	Ca	Mg	Na	K	HCO_3	CO_3	Cl	SO_4	Hardness	%Na (epm)	SAR (epm)
1.	Sultan Ghari's Tomb, Vasant Kunj	300	8.2	192	38.47	5.84	25.40	1.00	70.00	10.00	42.60	154.72	120.00	32.01	1.00
2.	Jawaharlal Nehru University	400	7.9	256	35.27	2.9	126.48	1.00	30.00	25.00	65.32	148.14	100.00	73.42	5.50
3.	Hamdard Public School, Talimabad	400	8.1	256	51.30	4.87	79.45	4.00	30.00	10.00	99.40	172.00	148.00	84.89	2.84
4.	Jamia Hamdard University, Hamdard Nagar	500	8.6	320	24.04	14.61	160.54	3.00	50.00	40.00	99.40	103.69	120.00	74.61	6.37
5.	Pushp Bhawan, Pushp Vihar	700	8.3	448	32.06	29.23	203.78	7.00	40.00	30.00	213.00	204.92	200.00	69.31	6.26
6.	Seva Bhawan, R.K. Puram	700	8.4	448	48.09	15.59	160.54	3.00	90.00	10.00	130.64	52.62	184.00	65.72	5.14
7.	Centre for Soil and Material Research, Ber Sarai	700	8.4	448	33.66	33.13	176.75	5.00	60.00	10.00	119.28	91.35	220.00	63.95	5.15
8.	Safdarjung Hospital	800	8.4	512	48.09	14.61	144.32	4.00	50.00	25.00	193.12	172.83	180.00	63.91	3.28

9.	Hotel Hayat	500	7.8	300	37.20	2.82	130.40	1.00	40.00	25.00	72.40	140.14	120.00	73.17	4.72
10.	National Institute of Health and Family Welfare, Munirka	400	8.5	256	40.08	16.56	101.08	2.00	30.00	20.00	82.36	116.04	168.00	56.94	2.84
11.	Indian Institute of Technology	600	8.4	340	41.10	16.40	105.90	2.00	30.00	25.00	80.25	120.53	160.00	57.79	3.53
12.	Vayusenabad, Khanpur	500	7.1	320	24.04	1.94	122.70	4.00	30.00	30.00	76.68	160.95	168.00	80.00	6.47
13.	Abul Fazal Enclave	1200	8.7	768	28.24	8.60	190.16	8.00	95.00	BDL	145.09	98.63	280.00	50.07	4.02
14.	Okhla Head	1800	8.5	1152	40.46	99.01	280.80	79.00	80.00	BDL	298.65	202.46	450.00	58.34	5.41
15.	Jamia Nagar	900	8.6	576	49.22	48.62	50.00	13.00	60.00	BDL	40.03	395.43	320.00	27.97	1.21
16.	Dhoula Kuan	600	8.1	384	35.92	30.91	80.00	2.00	40.00	BDL	180.62	279.94	300.00	44.88	2.36
17.	Taj Enclave	3600	7.9	2176	BDL	BDL	379.06	18.00	BDL	BDL	308.63	493.62	BDL	100.00	-
18.	Kalindi Kunj	1800	8.7	1152	25.25	140.62	203.24	32.00	145.00	BDL	194.16	78.43	620.00	42.96	3.47
19.	Jasoula	800	8.1	512	52.16	19.18	52.30	5.00	45.00	BDL	70.04	97.00	180.00	36.49	1.57
20.	Vasant Vihar	500	8.1	320	32.08	9.83	30.46	3.00	35.00	BDL	29.43	160.43	150.00	36.77	1.20
	Average	885	8.2	556.80	37.72	31.17	132.96	9.85	52.63	21.66	146.00	175.26	211.57		

Table-7: Physico-chemical parameters and hydrochemical data of the groundwater samples (mg/L) (Post-monsoon Nov.-Dec. 2004)

Sm. No.	Location	EC µS/cm	pH	TDS	Ca	Mg	Na	K	HCO_3	CO_3	Cl	SO_4	Hardness	%Na (epm)	SAR (epm)
1.	Sultan Ghari's Tomb, Vasant Kunj	600	8.7	384	88.17	24.36	20.00	BDL	30.00	BDL	82.36	148.40	320.00	11.96	0.48
2.	Jawaharlal Nehru University	700	8.3	448	41.68	38.00	110.00	3.00	50.00	BDL	51.12	129.21	260.00	48.29	2.96
3.	Hamdard Public School, Talimabad	700	8.3	448	68.93	19.49	100.00	4.00	BDL	60.00	76.68	168.71	252.00	46.88	2.73
4.	Jamia Hamdard University, Hamdard Nagar	800	8.8	512	40.08	19.49	240.00	8.00	BDL	BDL	88.04	68.30	180.00	74.71	7.77
5.	Pushp Bhawan, Pushp Vihar	1100	8.7	704	60.92	42.88	230.00	7.00	60.00	BDL	204.48	123.45	328.00	61.28	5.52
6.	Seva Bhawan, R.K. Puram	900	8.4	576	44.88	50.67	230.00	8.00	BDL	BDL	142.00	169.53	320.00	61.43	5.58
7.	Centre for Soil and Material Research, Ber Sarai	1000	8.1	640	43.28	15.59	20.00	BDL	20.00	BDL	22.72	78.18	172.00	20.17	0.66
8.	Safdarjung Hospital	1000	8.7	640	51.30	56.52	190.00	6.00	40.00	30.00	173.24	90.53	360.00	53.88	4.35

9.	Hotel Hayat	700	8.5	448	40.00	40.42	100.00	2.00	60.00	BDL	60.20	123.21	250.00	45.26	2.66
10.	National Institute of Health and Family Welfare, Munirka	800	8.5	512	67.33	29.23	120.00	4.00	70.00	BDL	76.68	160.48	288.00	48.00	3.07
11.	Indian Institute of Technology	800	8.4	512	65.25	25.20	115.00	3.00	60.00	BDL	80.60	155.43	260.00	48.79	3.10
12.	Vayusenabad, Khanpur	900	8.4	576	72.14	19.49	160.00	7.00	BDL	20.00	99.40	120.98	260.00	57.84	4.31
13.	Abul Fazal Enclave	1000	8.8	640	35.27	19.63	230.00	14.00	90.00	BDL	176.08	112.75	460.00	52.93	4.66
14.	Okhla Head	1700	8.7	1088	52.90	114.02	270.00	90.00	100.00	BDL	340.80	284.75	600.00	53.88	4.79
15.	Jamia Nagar	800	8.8	512	59.31	56.52	40.00	16.00	70.00	BDL	62.48	457.58	380.00	22.02	0.89
16.	Dhoula Kuan	1200	8.6	768	40.08	90.63	90.00	14.00	80.00	BDL	213.00	309.44	472.00	31.12	1.34
17.	Taj Enclave	3500	8.3	2240	BDL	BDL	405.00	22.00	BDL	BDL	255.00	592.88	BDL	100.00	-
18.	Kalindi Kunj	1800	9.1	1152	28.85	159.83	250.0	38.00	150.00	BDL	255.00	114.39	728.00	44.81	4.02
19.	Jasoula	800	8.3	512	60.92	26.31	50.00	7.00	40.00	BDL	85.20	160.95	260.0	31.14	1.34
20.	Vasant Vihar	700	8.6	448	66.83	20.18	30.00	2.00	35.00	BDL	68.16	160.40	280.00	21.35	0.82
	Average	1075	8.5	668	54.11	50.97	150.00	14.16	63.66	36.66	116.05	186.58	338.42		

Table-8: Concentration of trace elements in groundwater sample (ppm)
(Pre-monsoon May 2004)

S.No.	Zn	Pb	Cu	Fe	Mn	Cr	Ni	Co
1.	0.4378	0.2916	0.0473	1.6777	0.0468	0.1666	0.1071	0.1304
2.	0.1459	0.0833	0.0426	0.1333	0.0156	0.2500	0.0857	0.0326
3.	0.0036	0.1137	0.0431	0.1617	0.0142	0.3033	0.0399	0.0296
4.	0.0148	0.0833	0.0521	0.1333	0.0233	0.3333	0.0642	0.1467
5.	0.3003	0.0645	0.0264	0.1481	0.0048	0.1550	0.0465	0.0303
6.	0.143	0.0633	0.0252	0.2786	0.0118	0.3880	0.0814	0.0123
7.	0.2302	0.0499	0.0341	1.0333	0.0391	0.2499	0.0642	0.0294
8.	0.0421	0.1733	0.0246	0.5026	0.0121	0.2166	0.0445	0.0339
9.	0.1369	0.0744	0.0432	0.1238	0.0172	0.2134	0.0758	0.0346
10.	0.2164	0.0187	0.0298	0.1399	0.0140	0.3749	0.0578	0.0440
11.	0.2118	0.0167	0.0262	0.1239	0.0148	0.3116	0.0667	0.0436

12.	0.0043	0.1333	0.0227	0.2044	0.0156	0.5333	0.0685	0.0391
13.	0.1903	0.2116	0.0376	1.0339	0.2045	0.8240	0.1434	0.1495
14.	0.155	0.1316	0.0579	0.4508	0.1439	0.4315	0.1025	0.1533
15.	0.1830	0.1636	0.0085	0.4134	1.0461	0.2903	0.0712	0.0462
16.	0.0130	0.1869	0.0455	1.4627	0.6947	0.1443	0.0243	0.0683
17.	0.4080	0.1076	BDL	0.1480	0.0834	0.5438	0.1331	0.0323
18.	0.3041	0.0980	BDL	0.2521	0.9462	0.3017	0.1151	0.1021
19.	0.1025	0.1536	BDL	0.1600	0.0285	0.0724	0.0492	0.0611
20.	0.2055	0.1420	0.3124	0.3106	0.0314	0.8001	0.1246	0.0894
Av.	0.1659	0.1180	0.0439	0.4392	0.1704	0.3448	0.0782	0.0638

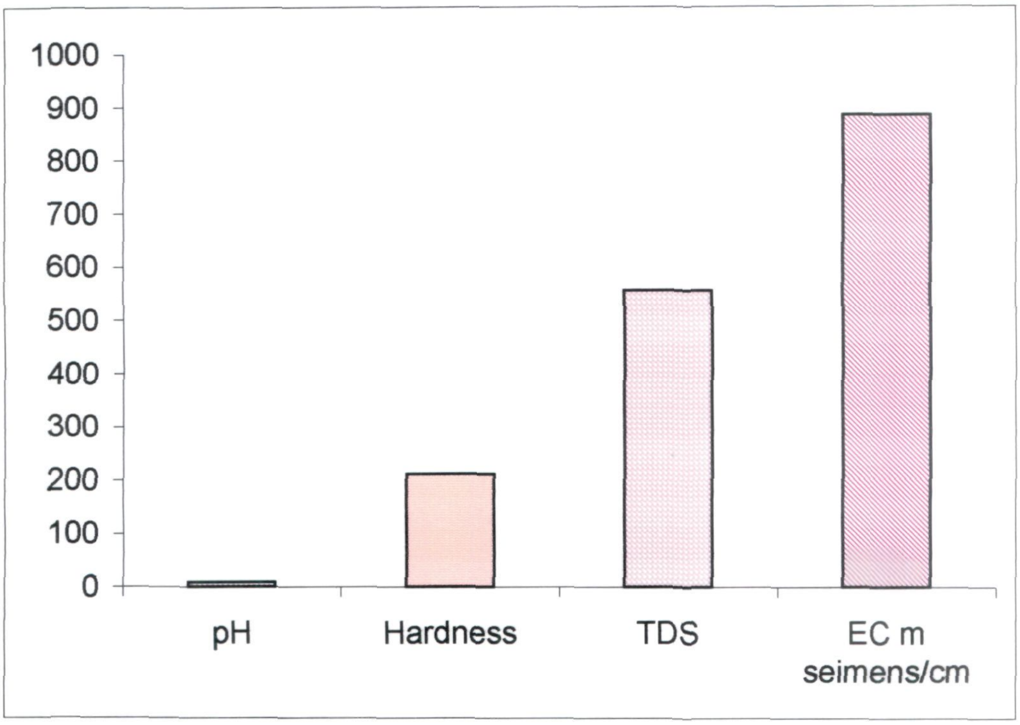
Table-9: Concentration of trace elements in groundwater samples (ppm)
(Post-monsoon Nov.-Dec. 2004)

S.No.	Zn	Pb	Cu	Fe	Mn	Cr	Ni	Co
1.	0.1885	0.1125	0.0341	0.3600	0.0210	0.9000	0.1157	0.0733
2.	0.0586	0.0291	0.0232	0.2022	0.0984	0.3500	0.0599	0.0570
3.	0.3480	0.0708	0.0402	2.3800	1.6601	0.2275	0.0910	0.1385
4.	0.1495	BDL	0.0298	0.1999	0.0281	0.4500	0.1157	0.0586
5.	0.0778	0.1874	0.0298	0.1699	0.0351	0.2250	0.0771	0.1173
6.	0.0513	BDL	0.0331	0.2777	0.0078	0.2250	0.0642	0.1304
7.	0.8432	0.0833	0.0473	3.4777	1.6171	0. 7500	0.0857	0.0652
8.	0.6871	0.3124	0.3198	2.9166	1.7636	1.0624	0.1285	0.0855
9.	0.0516	0.0317	0.0341	0.2146	0.0976	0.2894	0.0621	0.0556
10.	0.0964	0.2479	0.0281	0.3022	0.0421	0.4958	0.0910	0.0970
11.	0.0869	0.2389	0.0246	1.0444	0.0412	0.4856	0.0899	0.0962

12.	0.2128	0.0749	0.0255	0.1499	1.7578	0.2250	0.0771	0.1027
13.	0.2905	0.2083	0.0189	1.0444	0.1953	0.7500	0.1285	0.1467
14.	0.0506	0.1562	0.0284	0.4999	0.1289	0.4374	0.1125	0.1344
15.	0.1247	0.1116	0.0061	0.3250	1.0207	0.2708	0.696	0.0529
16.	0.0302	0.1000	0.0341	1.5377	0.6375	0.1333	0.0257	0.0586
17.	0.6675	0.0791	BDL	0.1583	0.0964	0.5541	0.1221	0.0929
18.	0.2733	0.0875	BDL	0.2022	0.8968	0.2916	0.1050	0.0798
19.	0.0628	0.2187	BDL	0.1666	0.0234	0.0687	0.0321	0.0611
20.	0.1666	0.1488	0.0214	0.3460	0.0316	0.9101	0.1258	0.0943
Av.	0.2175	0.1241	0.0389	0.7987	0.5100	0.4450	0.0889	0.0899

Figure – 11

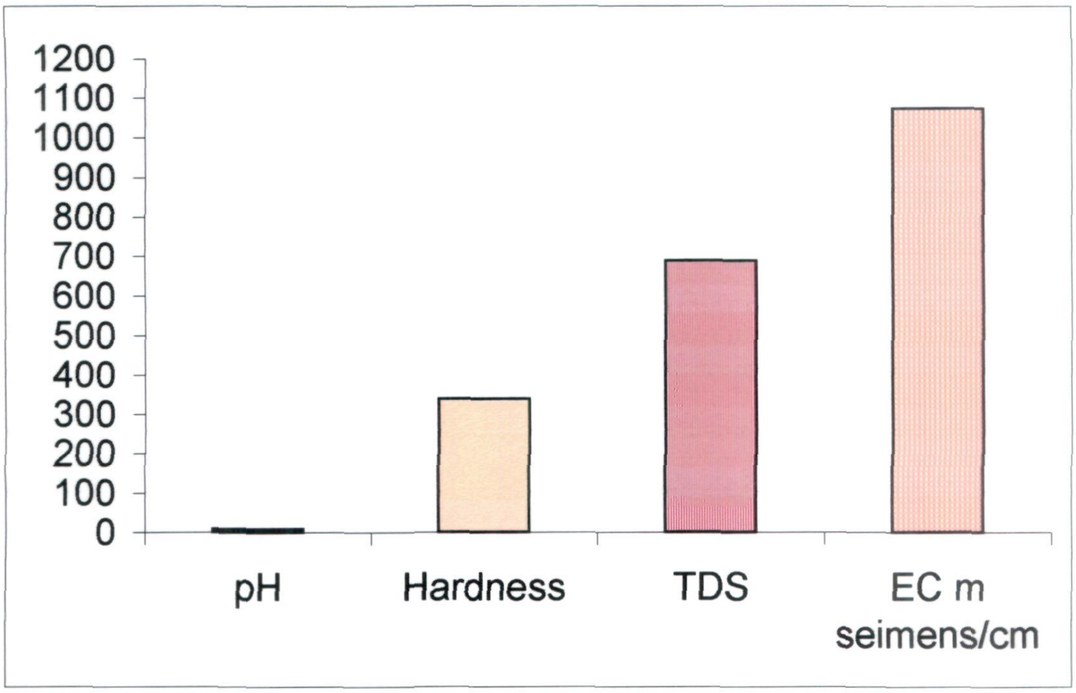
Average concentrations (in ppm)



Graph showing physico-chemical parameters and average concentrations of major ions in ground water samples (Pre-monsoon, May 2004).

Figure – 12

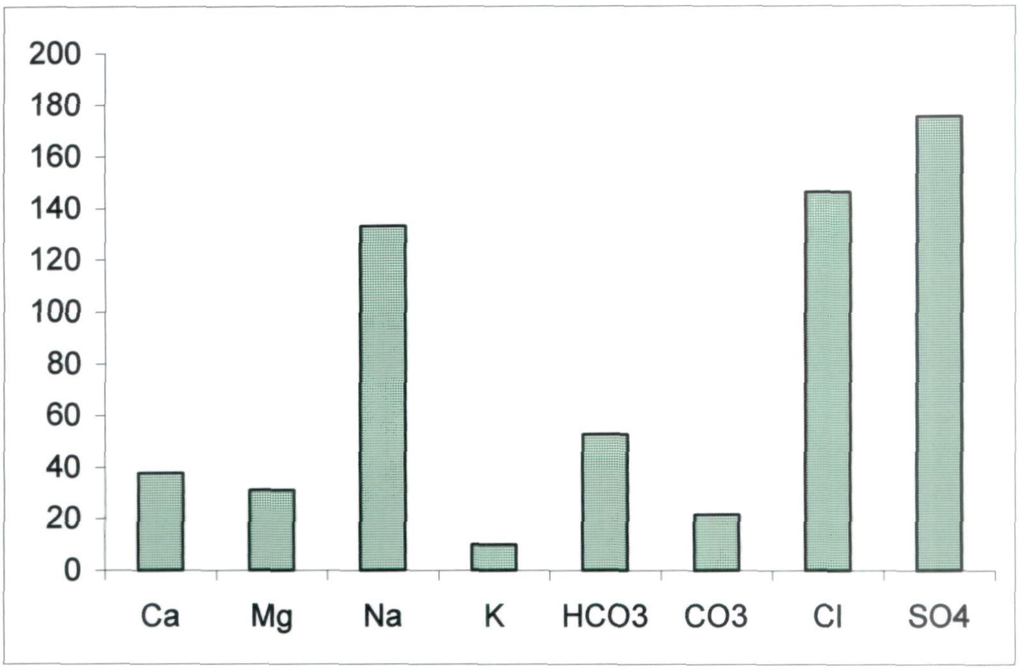
Average concentrations (in ppm)



Graph showing physico-chemical parameters and average concentrations of major ions in ground water samples (Post-monsoon, Nov. – Dec. 2004).

Figure – 13

Average concentrations (in Mg/l)

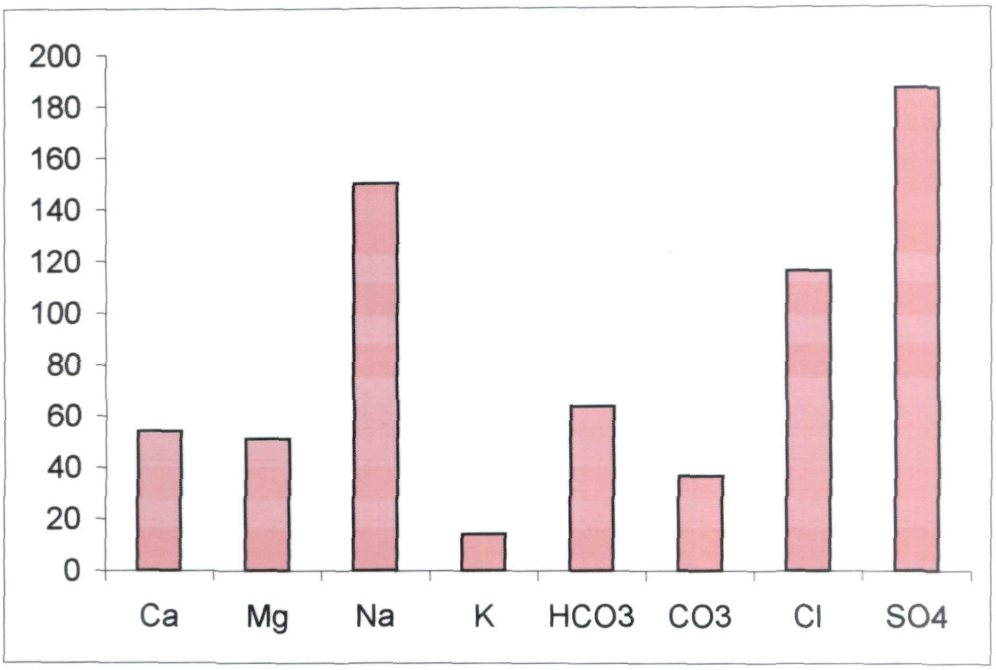


Major Ions

Graph showing concentration of major ions in ground water samples (Pre-monsoon, May 2004).

Figure – 14

Average concentrations (in Mg/l)

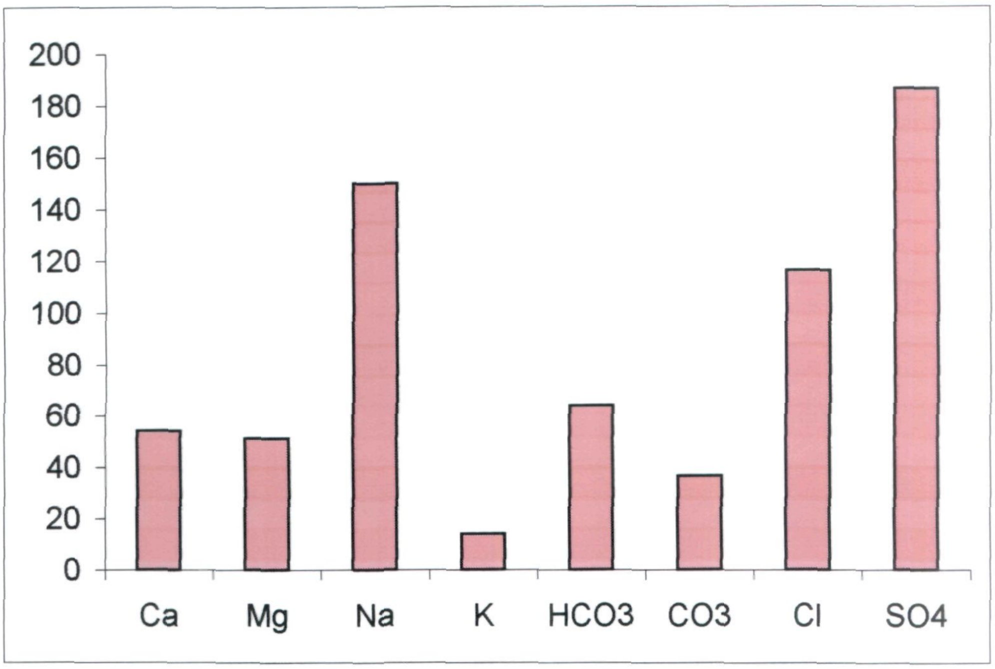


Major Ions

Graph showing concentration of major ions in ground water samples (Post-monsoon, Nov. – Dec. 2004).

Figure – 14

Average concentrations (in Mg/l)

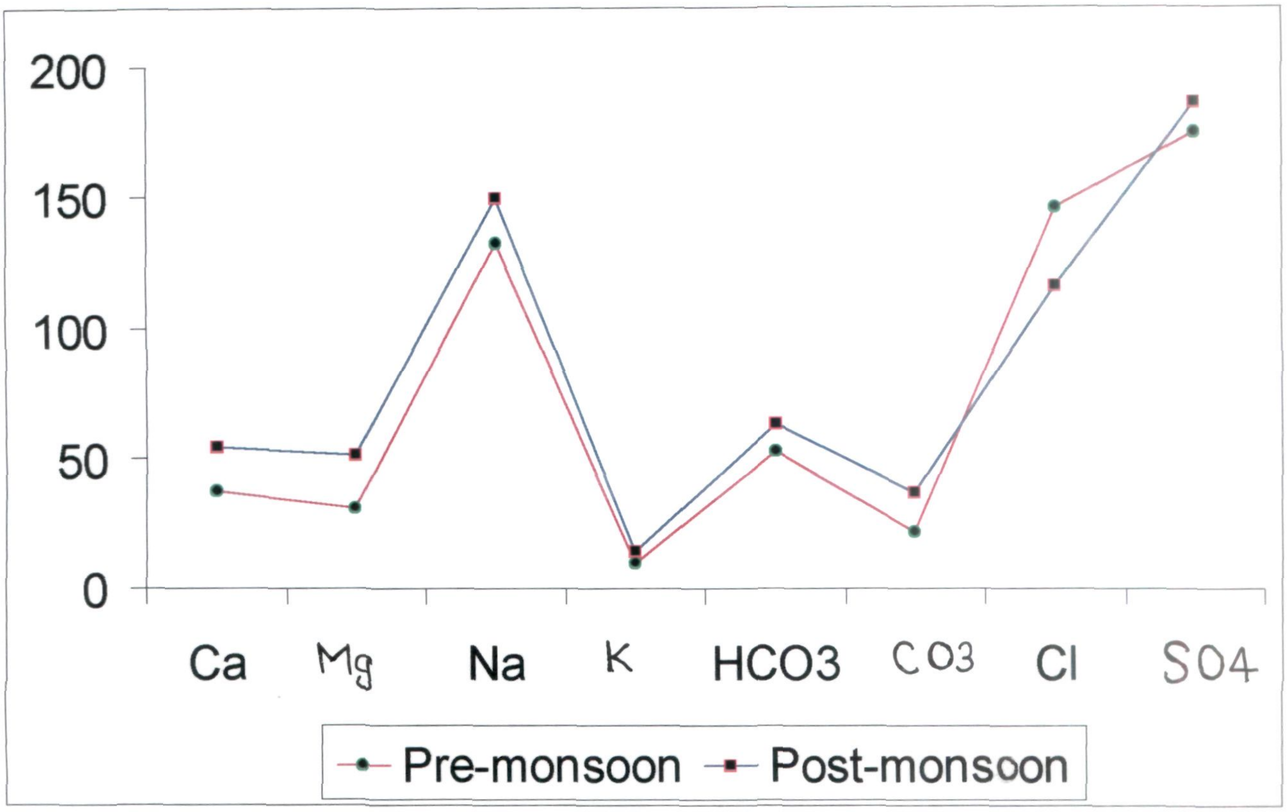


Major Ions

Graph showing concentration of major ions in ground water samples (Post-monsoon, Nov. – Dec. 2004).

Figure – 15

Average concentrations (in Mg/l)



Major Ions

Comparison graph of Pre-monsoon and Post-monsoon showing concentrations of major ions in ground water samples.

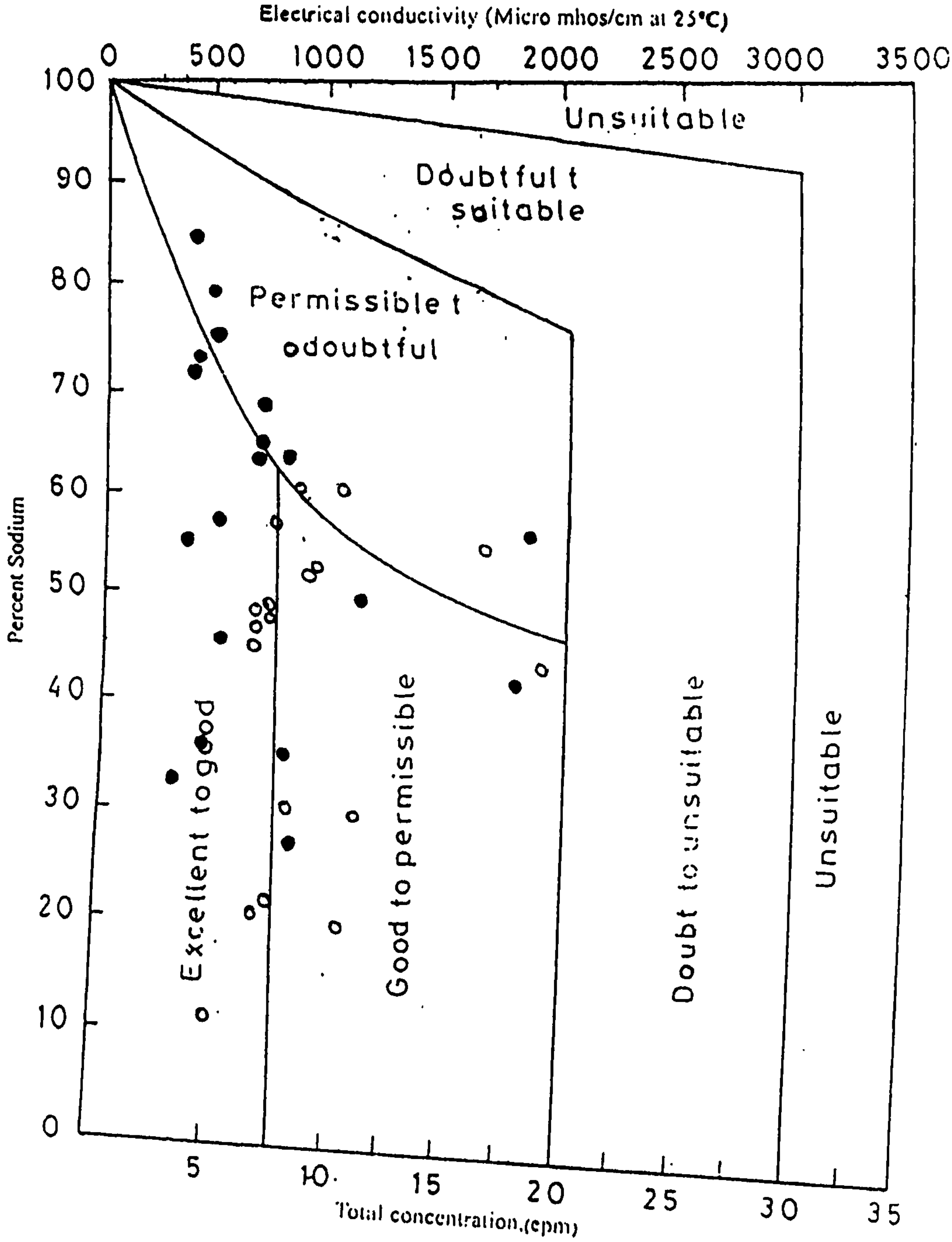


Figure-16. Quality classification of water for irrigation (Wilcox, 1955) Pre-monsoon and Post-monsoon, 2004.

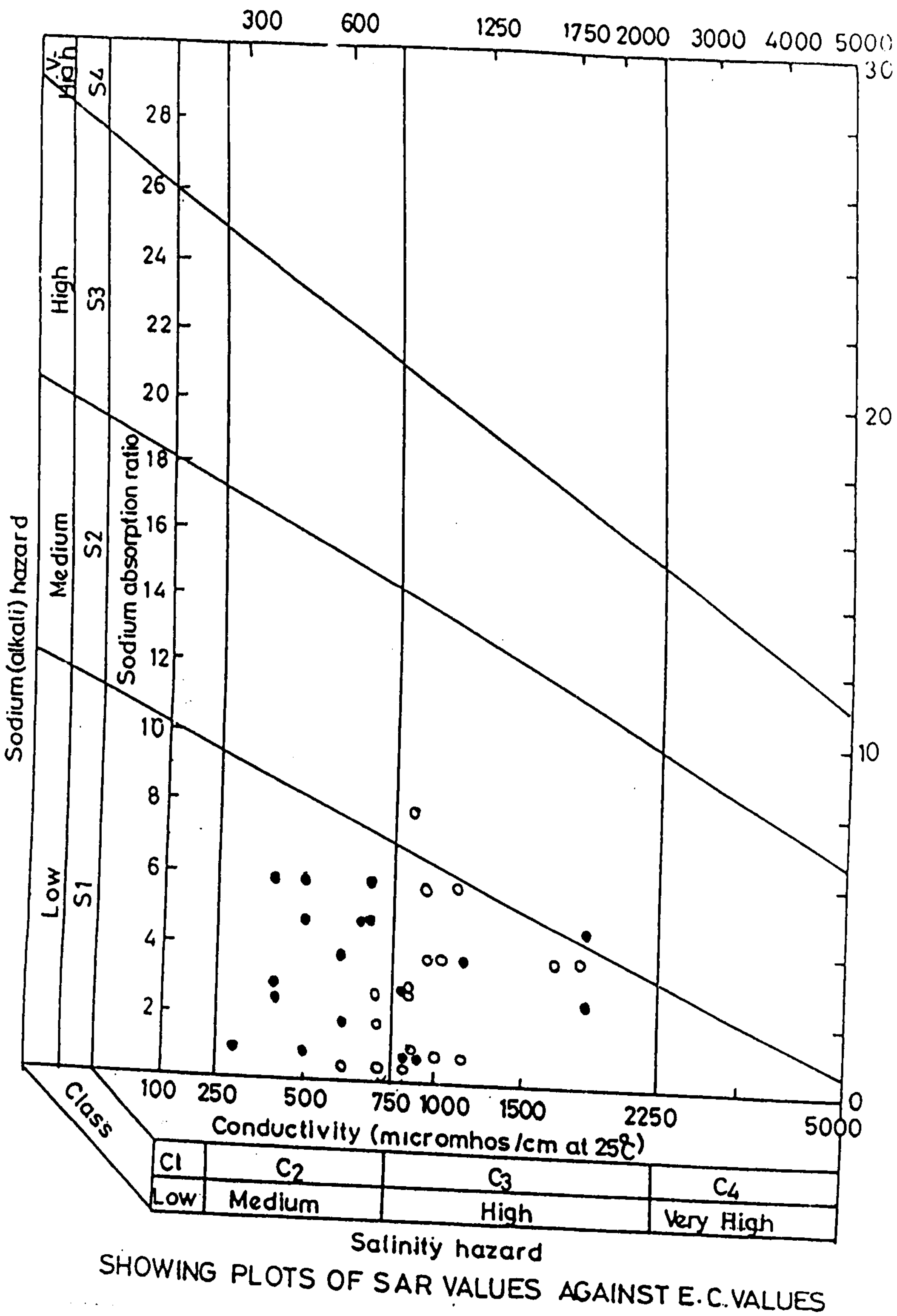


Figure-17. U.S. Salinity diagram for classification of irrigation of water (Pre-monsoon and Post-monsoon, 2004).

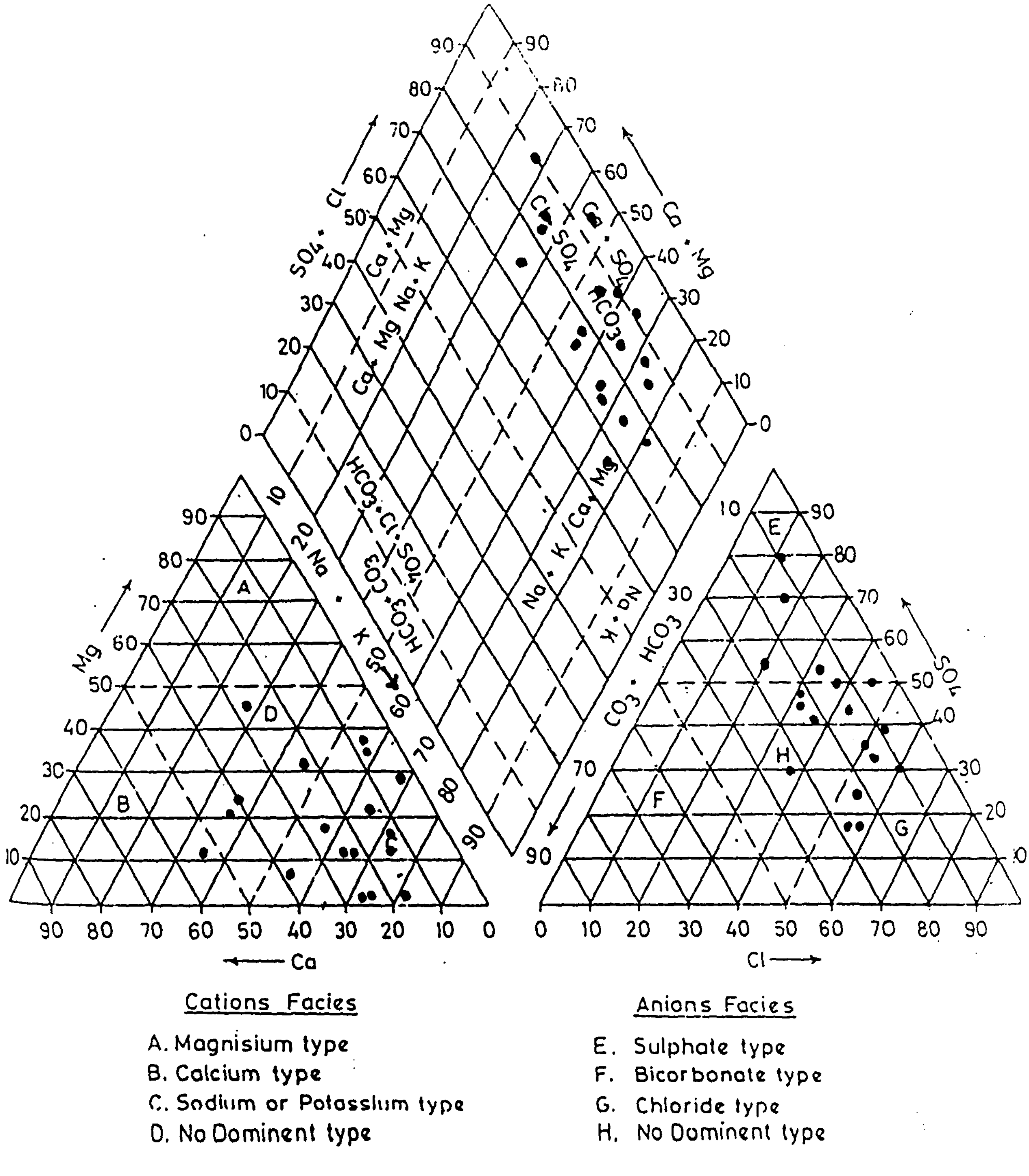


Figure-18. Piper trilinear diagram showing chemical characteristics of water (Pre-monsoon period May, 2004).

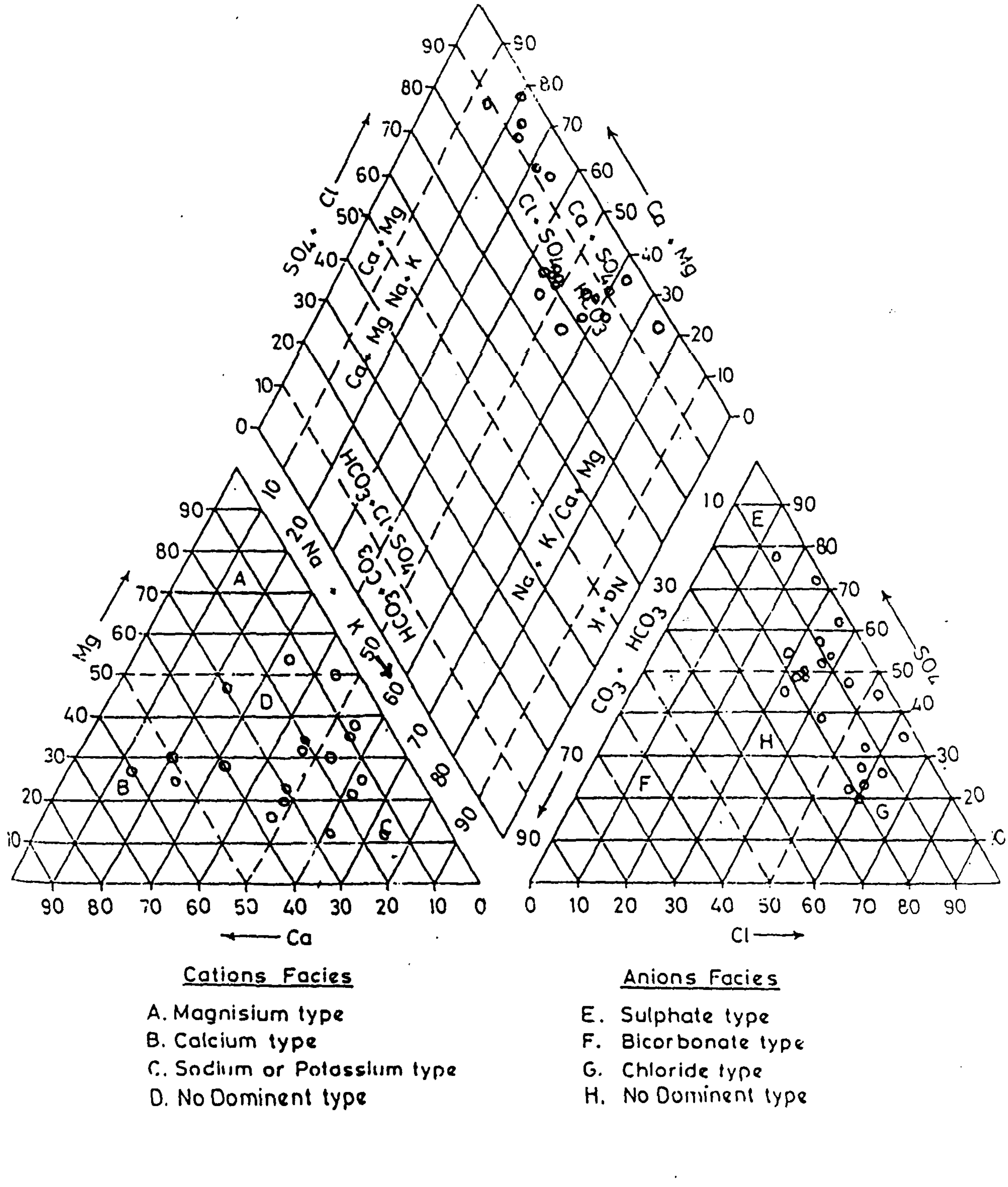
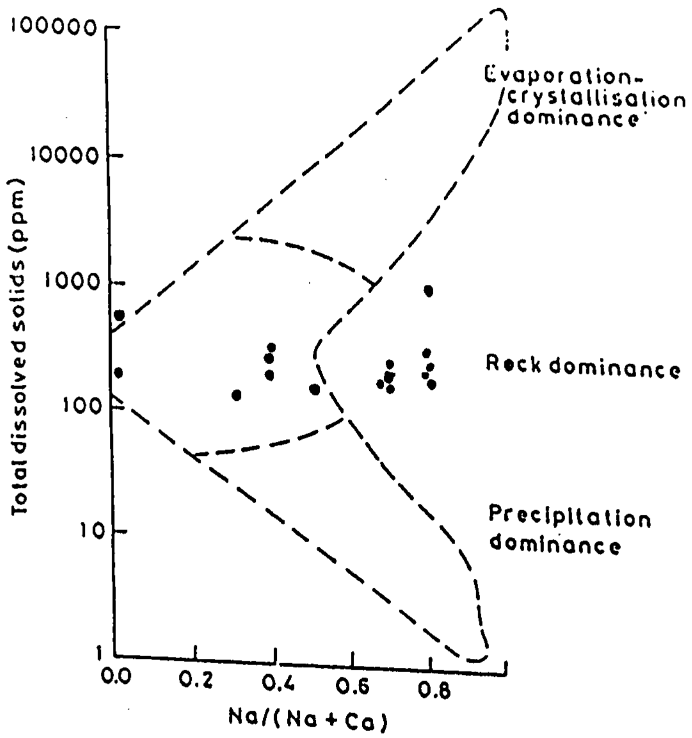


Figure-19. Piper trilinear diagram showing chemical characteristics of water (Post-monsoon period Nov.-Dec., 2004).



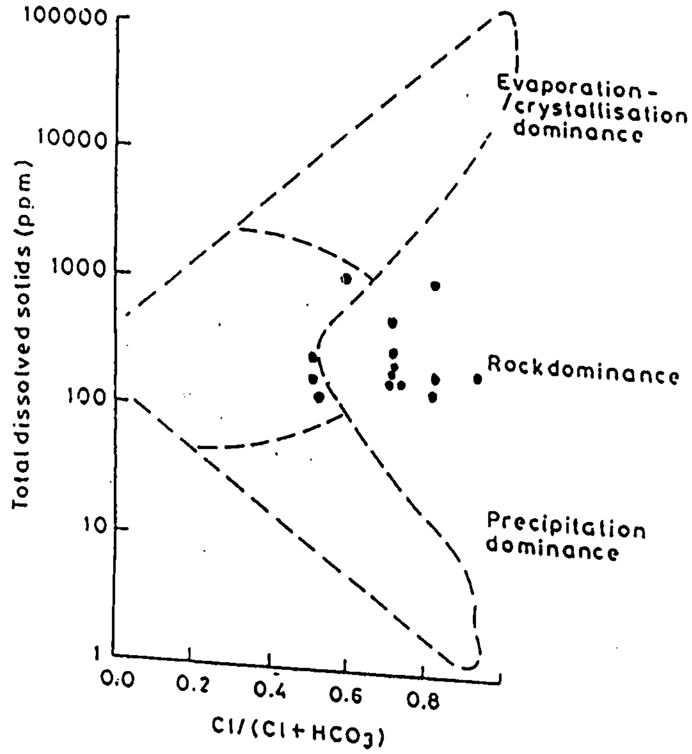
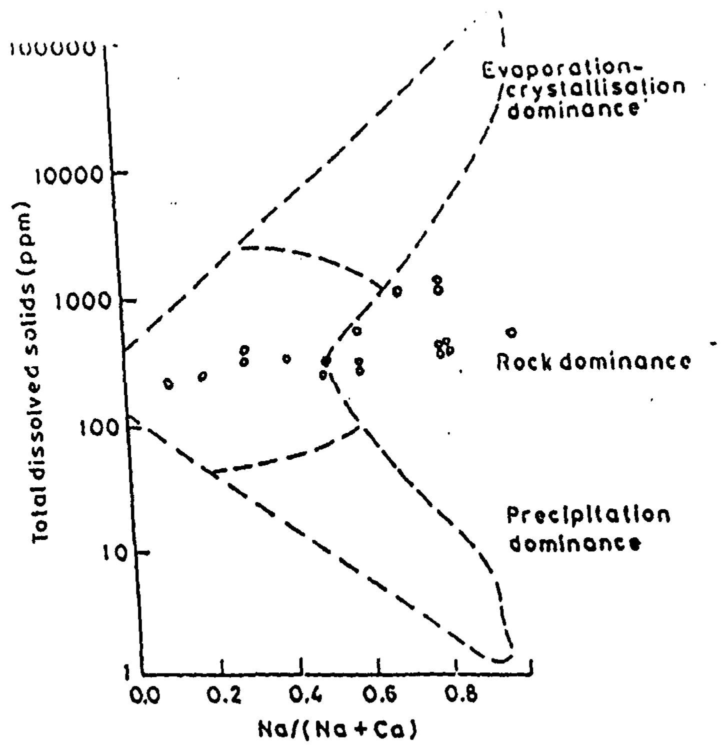


Figure-20. Chemical data for groundwater plotted in accordance with the scheme of Gibbs (1970) Pre-monsoon, May 2004.



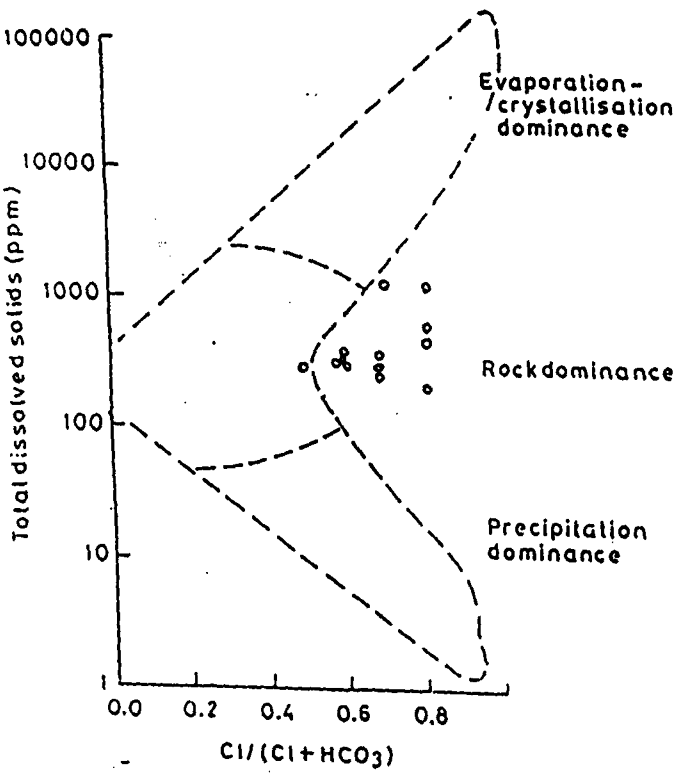


Figure-21. Chemical data for groundwater plotted in accordance with the scheme of Gibbs (1970) Post-monsoon, Nov.-Dec., 2004.

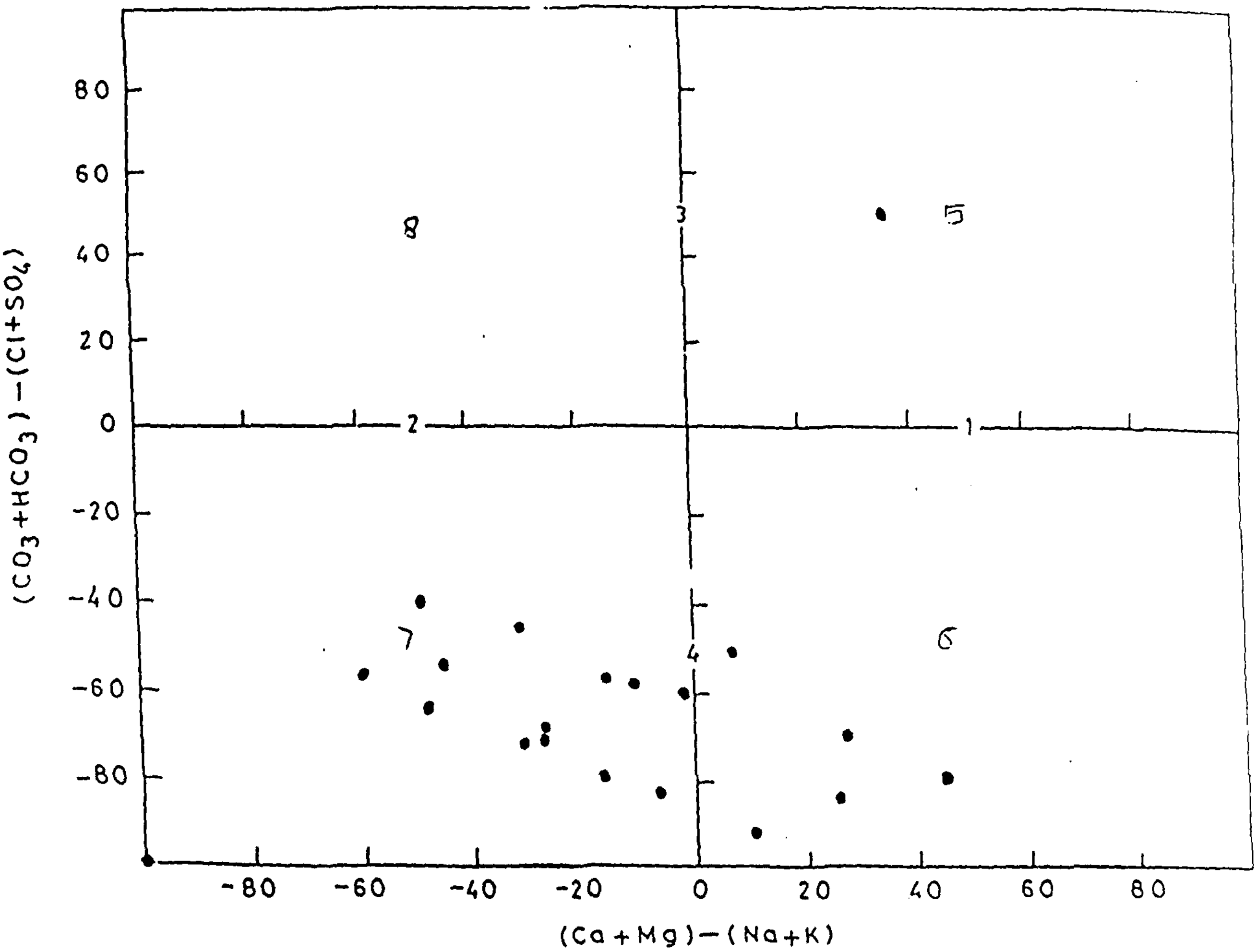


Figure-22. Modified piper diagram of Geochemcial classification of groundwater samples (after Chadda, 1998) Pre-monsoon, May 2004).

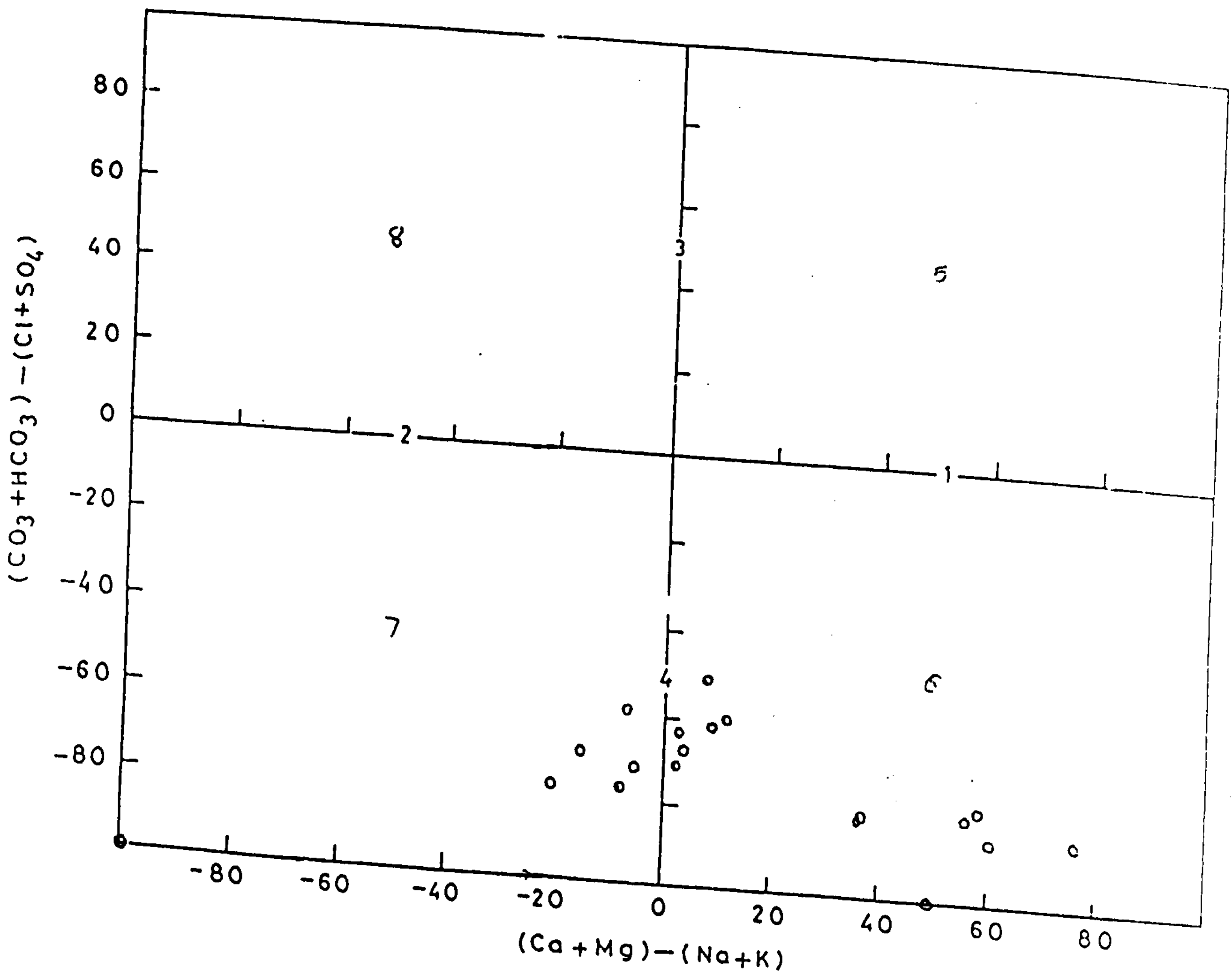
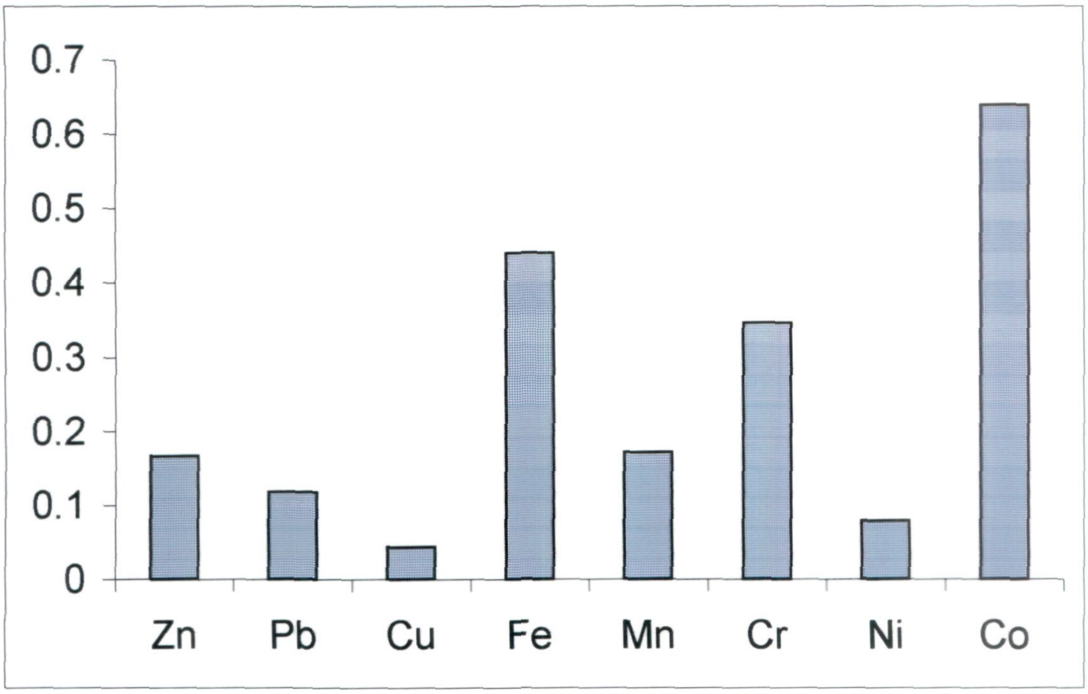


Figure-23. Modified piper diagram of Geochemcial classification of groundwater samples (after Chadda, 1998) Post-monsoon, Nov.-Dec., 2004).

Figure – 24

Average concentrations (in ppm)

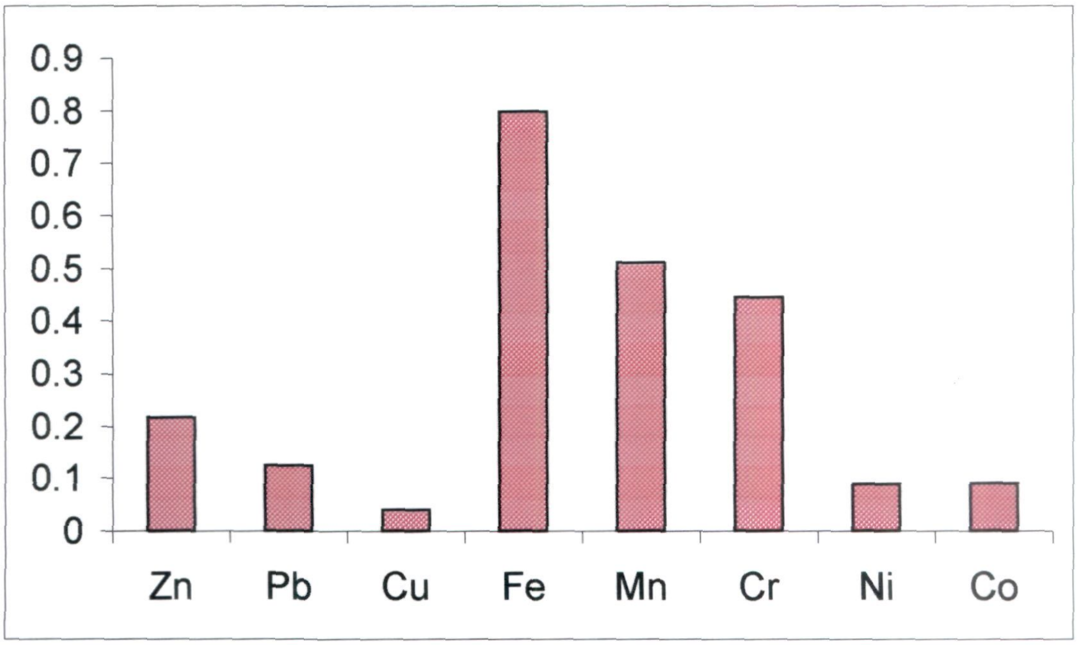


Trace elements

Graph showing concentration of trace elements in ground water samples
(Pre-monsoon, May 2004).

Figure – 25

Average concentrations (in ppm)

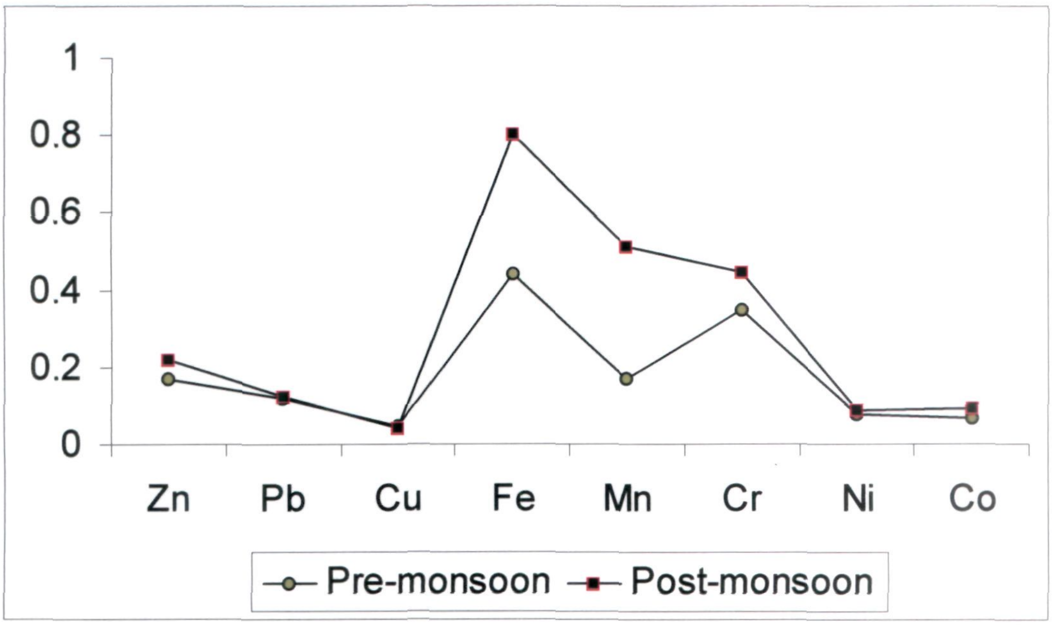


Trace elements

Graph showing concentration of trace elements in ground water samples (Post-monsoon, Nov. – Dec. 2004).

Figure – 26

Average concentrations (in ppm)



Trace elements

Comparison graph of Pre-monsoon and Post-monsoon showing concentrations of trace elements in ground water samples.

Chapter 6

Summary and Conclusion

SUMMARY AND CONCLUSION

Water is the most valuable intake necessary for the survival of life on the earth water from surface and sub-surface sources provides sustenance to plants and animals, constitutes habitat for aquatic organism and meets important agriculture and industrial needs. For much of the land surface the critical problems of water use are related to its limited volume, fluctuations in its flow from season to season and continuous degradation of water quality.

The demand of water has been increased in manifold. With the growth of science and technology, new types of industries come with new materials to make our life more comfortable, but at same time pollute the surface and groundwater unless appropriate preventive measures are taken.

As the groundwater system is the sole source for public water supply and there are no immediate realistic alternative sources. To augment the groundwater resources in the study area various artificial recharge techniques have been used on a large scale in NCT, Delhi. It is necessary to carryout systematic study about hydrochemistry and groundwater development of the area. The study is conducted in order to make groundwater development, role of heavy metals and concentration of major ions in groundwater samples.

The impact of rainwater harvesting on groundwater quality as well as groundwater development in the South of NCT, Delhi. Detailed information about various chemical characteristics, temporal changes in water quality and variation in chemical characteristics with increase in depth with other features. The systematic study of the chemical nature of sub-surface water bodies has been made to find out the quality of water bodies in references to drinking, agriculture as well as industrial purposes.

In some part of the study area the water level has been declined rapidly as much as 10 metres over the past years in South of Delhi. The lowest water level has been noticed in Jamia Hamdard University, 59.64 m bgl during the pre-monsoon period in 2004.

The area falls, under the sub-tropical climate zone with extremes in summer and winter. The mercury shoots upto 44°C or even more during May every year and drops to below 5°C during January. The normal annual rainfall in NCT, Delhi is 611.8 nm. About 85% of the total rainfall occurs in the months of July and August.

The Ganga basin of Indo Gangetic plain forms the largest groundwater reservoir in India, and is considered to be formed as a result of continent-continent collision between Indian and Asian plates. The study area is occupied by Quaternary alluvium and Pre-Cambrian Alwar Quartzite of Delhi supergroup. Quaternary alluvium overlies unconformably the Alwar Quartzite and covers major parts of the study area. For different hydrogeological environments viz. alluvial plain on eastern and western side of the ridge, Yamuna flood plain, Chattarpur alluvium basin and Quartzitic ridge control movement and occurrence of groundwater. During the month of May, 2004, depth to water levels in South Delhi are in the range of 10.30 m bgl to 5.964 m bgl and Southwest districts vary from 5-43 m bgl. In the southeast district 5-12 m bgl. Quality of groundwater is fresh at shallow depth and deteriorates with increasing depth. The increasing trend in water level during post-monsoon period Nov.-Dec. 2004 has been observed almost in the all hydrographic stations except Sultan Ghari. The water level shows increasing trend at Vasant Vihar about 3.59 m bgl.

Prior to the implementation of the rainwater harvesting system. The groundwater level increased from 1.0 m bgl – 3.5 m bgl. The present available surface water sources are about 1150 MCM, out of which 724 MCM water is available from river Yamuna. Out of this, 724 MCM, the monsoon runoff is 580 MCM. About half of this runoff that is 282 MCM has been calculated as wastage. This added to 193 MCM surface runoff generated from rainfall on MCT Delhi makes about 475 MCM and can be used for recharging the aquifer system. Areas feasible for artificial recharge to groundwater has been demarcated based on the depth to water level and showing decline trend in water levels. The areas where water level is more than 8 metre below ground level and showing continuously declining trend are identified as most suitable areas for taking up artificial recharge to groundwater. The deeper water levels are found in South Delhi, thickness of unsaturated zone in Tughlakabad, Okhla, Khanpur, Pushp Vihar, varies from 35-40 metres. Very potential unsaturated aquifer system is available in NCT Delhi to be utilized for recharging after the implementation of artificial recharge structure the water level rises within the range of 2.0 to 4.0 metres.

The chemical quality of groundwater in the part of NCT, Delhi has been taken up from the analysis of twenty groundwater samples for study to evaluate its suitability for irrigation and drinking purposes. In general groundwater in the area is alkaline in nature and belongs to sodium or potassium type facies among the cations and chloride type or no dominant type facies among the anions. The salinity of groundwater is medium to high during pre-monsoon period. In the post-monsoon most of the samples fall in sodium or potassium type facies and no dominant type facies among the cation facies. Among the anions facies, majority of the samples belong to chloride type facies and sulphate type facies. Groundwater at all the locations is alkaline in nature. Gibbs (1970) variation diagram has been used to study the mechanism controlling water chemistry. It has been observed that water chemistry of the study area reflects the field of rock dominance.

From modified piper diagram, it has been observed that the majority of groundwater samples fall in the field of 6 and 7 indicating alkali metals exceeding alkaline earths and strong acid exceeding weak acid. Such water can be classified into high salinity group may cause salinity problem both in irrigation and domestic uses.

The maximum concentration of cations have been recorded at CSMR and minimum at Vasant Kunj. A high concentration of anions at Pushp Vihar and minimum concentration of anion at NIHF, during Pre-monsoon. The maximum concentration of cations have reported at Okhla head and minimum value observed at Vasant Vihar. The high concentration of anions has been observed at Okhla head and minimum concentration anions at CSMR.

Overall concentration of calcium, magnesium, sulphate, chloride within the permissible limit of WHO (1984) and ISI (1983) at most of the locations of South Delhi, except one location at Kalindi Kunj which has a value of 159.83 ppm and exceeds the maximum permissible limit of

WHO (1984) and ISI (1983). Sulphate and magnesium concentration has been found above the maximum permissible limit, for public water supply. The plots of sodium percent against electrical conductivity and sodium adsorption ratio values against electrical conductivity has a spatial variation in groundwater quality for irrigation water.

The chemical analysis of trace elements in water samples also of great concern to the groundwater quality.

The concentration of lead at least in 50% samples exceed the permissible limit prescribed by WHO (1984). The consequences of lead pollution in relation to the human health is one of the great concern because of higher content of this metal causes and their effects on skin and mental disorder. This alarming high concentration in water is due to extensive use of lead in printing, manufacturing of paints, water pipes and storage battery etc. in the study area.

Copper concentration is below the highest desirable limit. The concentration of iron exceed the highest desirable limit in all the groundwater samples.

The manganese (Mn) concentration is within the permissible limit in most of the samples but few groundwater samples show relatively high concentration. The chromium contents are higher in all the water samples and exceeds more percent compare to WHO (1984) and ISI (1983).

The concentration of nickel in groundwater samples is low. The concentration of nickel with an average value of 0.0782 ppm in pre-monsoon and average value in post-moon has been observed 0.0889 ppm. The high concentration of nickel is observed in post-monsoon period. It is observed from the analysis result that average value of trace elements such as (Zn, Pb, Cu, Fe, Mn, Cr, Ni and Co) in groundwater has been increased except copper.

From the analysis of water samples collected from the study area from different locations, it has been observed that the average concentration of trace elements were higher in post-monsoon in comparison to pre-monsoon.

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